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Impact of logging on fish habitat in belt geology streams

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The Impact of Logging on Fish Habitat In Belt Geology Streams

by

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ABSTRACT

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Disturbances caused by logging may result in significant changes to fish habitat and channel structure. Common habitat disturbances include the alteration of volume, rate, and timing of sediment and water and changes in large woody debris. To evaluate habitat impacts from logging, six paired watersheds (1-3 order) on the Lolo National Forest were surveyed. Disturbances ranged from 18-53% of the basin harvested and occurred 18-22 years before the survey. Substrate composition, riparian and habitat structure, and woody debris were evaluated using a modified Hankin and Reeves methodology. Stream temperature and a "WATSED" model also evaluated basin disturbance. Types of pool formation, pool and riffle numbers, and habitat types were similar within paired streams. Harvested basins held significantly wider channels, larger pools, and deeper habitats, but not significantly longer habitat lengths or riffle areas compared to control streams. Habitat and channel features remained relatively unaffected because channels were not cleared of LWD; water yields were insufficient to cause channel change, and structural channel features were very stable. Channel modifications were limited to areas where significant streamside logging decreased rootwad and bank stability. Harvested streams held significantly more active LWD, had less riparian potential LWD but similar LWD lengths, diameters, formation types and inactive debris densities compared to control streams. Riparian harvests resulted in significantly reduced canopy closures, earlier successional stages and changed overstory compositions. The greatest impact to LWD and riparian features occurred in streams having more than 60% of their riparian zone harvested. Streams with over 60% of their riparian zone harvested showed the greatest impact to LWD and riparian features. Stream substrate composition and temperature were not significantly different between logged and unlogged basins. This was probably due to the extensive time that passed since disturbances occurred.

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INTRODUCTION

Small headwater streams in Western Montana provide important spawning and rearing habitat for westslope cutthroat (Salmon clarki lewisi) and bull trout (Salvelinus confluentus). Both species depend upon stable, high-quality habitat. Habitat is in turn a product of geology and soils, topography, vegetation, climate, and hydrology of a watershed (Meehan, 1991). As long as watershed characteristics remain fairly constant so should the productivity of aquatic habitat.

Timber harvest can have variable effects on watershed condition, thus impacts on fish habitat can be very elusive. On-site alterations may not always have a downstream effect. Furthermore, if an effect occurs, it may be difficult to determine its cause because the change is spatially removed or temporarily delayed (Grant, 1988).

Common basin-level disturbances associated with logging includes alteration of channel structure, increased sedimentation, increased water temperature and alteration of basin hydrology (Beschta 1978; Chamberlin et al., 1991). For example, harvesting and road construction can accelerate the input of sediment and concentrate water into streams (Cederholm et al. 1982). Increased sediment can cause the area, volume, and spacing of pools to be reduced (MacDonald, et al. 1991). Higher peak flows can also decrease channel stability. Harr et al. (1975)

concluded that peak flows may increase up to 45% due to clearcutting in small watersheds. This can reduce the survival of fish embryos due to bedload movement, cause fewer pools from bedload filling and lead to channel downcutting increasing sedimentation.

The characteristics of large woody debris (LWD) can also be altered by timber harvests. Timber harvests have been shown to change the frequency of large stable debris, change LWD distribution and reduce important sources of new debris (Bisson et al. 1987; Meehan 1991). This in turn can profoundly impact fisheries by reducing the complexity, spatial array, and stability of habitat features, especially pools (Keller and Swanson 1979; Bilby and Ward 1989).

Although previous studies documented logging effects on streams (Hall and Lantz 1969; Bilby 1984; Hogan 1986; Andrus et al. 1988), few examined impacts over entire stream lengths (confluence to headwaters). Many studies used the paired watershed approach, but they also used representative stream segments (Hogan 1986; Carlson et al. 1990). Small sections (segments) are often used to make inferences on stream condition as a whole; however such generalization can be misleading because channel gradient and confinement can quickly change. Thus, monitored parameters, influenced by gradient and confinement, may not reflect overall stream conditions.

The objective of this study was to compare the effects of logging on fish habitat between paired watersheds. All available fish habitat was surveyed, and no pair was farther than five miles (8.0 km) apart. Two hypotheses were proposed. First, that streams draining basins altered by timber harvests would exhibit channel, woody debris and riparian characteristics that would differentiate them from unlogged basins. Second, that fish habitat diversity would decrease with greater watershed and channel disturbance.

LITERATURE REVIEW

Introduction

To complement this study I have compiled a literature review on selected variables investigated in the field. For example, data were collected on size, placement, and function of woody debris in small streams. Thus, the literature review examines the role of woody debris in creating fish habitat, its function in controlling channel form, and impacts from its removal. Because information is widely scattered, the literature review will also help guide the reader to important studies that examine the effects of logging upon streams.

Statement of Intent

The following literature review is intended to inform the reader of specific ways that logging can impact aquatic resources. While I am aware of other impacts not covered in the literature review (invertebrates, oxygen depletion, redd survival, etc...) the review is designed to address only topics central to my study. This review is not inclusive, for such a task would require volumes to cover the subjects adequately.

Basin Hydrology

Changes in quantity, quality, or timing of stream flow can greatly affect resident fish populations. Specifically, harvesting activities such as roadbuilding, yarding, falling, and burning can alter watershed hydrology and stream flow. Severity of effects varies between watersheds because many variables ultimately determine hydrologic response. Some variables include: topography, geology, stand composition, nature of treatment, and post-treatment recovery.

Harvesting

Harvesting can affect a basin in two primary ways: (1) it reduces infiltration capacity by compacting soils during roadbuilding, skidding and hauling, and (2) it eliminates vegetation that would otherwise intercept precipitation. Careless logging can compact as much as 40 percent of a managed area, reducing infiltration from several inches per hour to a fraction of an inch (Handley, 1985). As a result, damaging overland flows occur during periods of high rainfall or snowmelt.

Harvested areas can be more prone to overland flow events, because dead roots are no longer able to extract soil moisture. Harr (1975) concluded that peak flows may increase up to 45 percent over natural due to clear-cutting. During storm events harvested areas contained wetter soils than unlogged areas which lead to higher groundwater tables.

Snow Distribution

Clear-cutting may increase snow deposition in forest clearings causing advances in the timing and rate of snowmelt (Chamberlin, et. al. 1991). Effects can last several decades until stand aerodynamics approach those of the surrounding forest. In the West Kootenay Mountains of British Columbia, snow accumulation in openings was 37 percent greater than in the forest and melted 38 percent faster (Toews and Gluns, 1986). Troendle and King (1985), found that peak snow water equivalent (depth of water that results when snow melts completely) averaged 9 percent higher, and peak snowmelt flows averaged 20 percent greater after a forest was harvested. Since soils in forest openings are wetter, melt water can percolate faster, resulting in earlier high peak flows (Chamberlin, 1982).

Higher Peak Flow

Higher peak flows can be detrimental to fish production because of greater erosional competence and increased gravel transport. Movement of gravel can reduce fish survival by scouring eggs and alevins from redds, or simply by jarring them during early development (Hall and Lantz, 1969). In contrast, changes in discharge may increase summer flows and improve fish habitat by increasing habitat area (Chapman, 1962). Average minimum daily summer flows increased by at least 78 percent after two post-logging years in Carnation Creek, British

Columbia (Hetherington, 1983). This increase lasted 3 to 5 years until new root systems developed.

Sedimentation

The quantity of sediment contributed to streams is directly related to the amount of bare, compacted soil exposed to rainfall and runoff (Meehan, 1991). Considerable research has been done on the sources and effects of sedimentation (Sullivan, 1987; Cederholm et al., 1982, Beschta, 1978; Brown and Krygier, 1970; Chapman, 1962). While some studies find fine sediment beneficial to salmonids by contributing to increased invertebrate productivity, most research indicates that fine sediment is detrimental to the life history of salmonids.

Roads

Logging roads and their unprotected cut and fill slopes are primary sources of sediment in forested watersheds (Chapman, 1962). Movement of sediment downslope from roads depend upon the amount and velocity of runoff, the availability of erodible soil, and the obstructions to sediment transport (Megahan and Kidd, 1972). Not all sediment eroded from roads reaches a stream channel, but roads do provide important pathways or sources (Meehan, 1991). For example, gravel-surfaced logging roads increased sediment by 40 percent when they were heavily used by logging trucks (Reid and Dunne, 1984). A six-year study of skyline logging with no roadbuilding was compared to watersheds containing only jammmer logging. Skyline logging increased sediment deposition by only 1.6 times; in contrast, jammer-logging with numerous roads increased deposition by 850 times for the six years after road construction (Megahan and Kidd, 1972).

Channel Influences

Sediment accumulation in stream channels can reduce stream depth and habitat diversity. A decrease in channel depth and an increase in channel width can have major adverse effects on biological communities. Usually increases in coarse sediment lead to accumulations of sediment in the deeper parts of stream channels (MacDonald, et al. 1991). Jackson and Beschta (1984), indicated that additional sand tends to be deposited in non-riffle stream locations, namely pools, backwater areas, and channel edges. Greater deposition may eventually reduce the depth, area, volume, and spacing of pools (MacDonald, 1991).

On the South Fork of the Salmon River, logging and road maintenance caused an influx of sand that filled many of the prime salmonid spawning and rearing areas (Megahan, 1982). Hogan (1986) also found that in logged watersheds pool-riffle spacing was reduced and riffle heights increased. This indicated that more sediment was delivered to the channel was moved out; therefore, the material was stored in riffles. Additional sediment resulted in proportionally larger riffles and smaller pools, which represented a reduction in available rearing habitat.

<u>Substrate</u>

The abundance and quality of spawning substrates can be severely affected by sedimentation. Fine sediment can be deposited in gravel interstices, even in fast-moving streams, because of lower water velocities within the gravels (Meehan, 1991). If the amount of fine material in the gravel matrix is too great, a cementing layer may form preventing gravel excavation by fish (Meehan, 1991). In the Clearwater River (Washington), the proportion of fines in spawning gravels remained constant when roads covered less than three percent of the basin area. However, when road area exceeded three percent, spawning gravel fines began to surpass unaffected levels (Cederholm et al., 1982). In Clearwater tributaries, such as Miller and Christmas Creeks, roads constitute six percent of the basin area, and fines in spawning gravels compose 15 to 20 percent of the substrate's composition (Cederholm et al., 1982).

Riparian Zone

Because of the close linkage between stream and terrestrial ecosystems, logging can have numerous affects on streams and their salmonid populations (Meehan, 1991). Moring et al. (1985) reviewed the relationship between of streamside vegetation and habitat and described five important riparian functions. These functions include: regulation of stream temperatures, stabilization of stream banks, provision of nutrients to streams, direct input of invertebrates as fish food, and provision of fish cover.

The influence of riparian vegetation varies with stream size. In headwater streams, small trees and brush can provide effective shading but farther downstream, even large trees may not provide effective shading. Small streams also receive more organic matter per unit stream area from local riparian vegetation than larger streams.

Harvesting Impacts

General watershed impacts resulting from timber harvesting are increased periphyton production after canopy removal, increased water temperature from canopy loss, bank erosion, and changes in allochthonous sources of organic matter for the stream. Each effect can negatively impact fisheries. For example, clear-cuts lacking buffer strips reduce winter carrying capacity for salmonids by reducing cover, collapsing undercut banks and embedding channel substrate (Murphy et al., 1986).

The response of salmonids to such changes in physical habitat depend on how channel alterations affect the "bottleneck" in fish production (Meehan, 1991). Bottlenecks represent the most restrictive phase of the salmonid life cycle. For example, increased primary production after canopy removal allows increased fry abundance in summer, but this increase may be nullified by a shortage of winter cover (Murphy et al., 1986). Removal of debris decreases winter cover and destabilizes the stream channel. More important, streams with impacted riparian zones can have limited inputs of organic debris which create critical winter habitat.

Channel Morphology

Physical features in stream channels are primary determinants of the type and quality of fish habitats. These physical features include: stream bed gradient, geology, water velocity, substrate, woody debris and water depth. Forest management can affect physical features by altering the amount and timing of sediment and water contributed to the stream, weakening channel banks and removing sources of large woody debris.

Channels undergo many subtle changes from season to season and year to year (Beschta, 1986). Some changes result from natural stream dynamics, others are induced by timber harvest activities. Headwater streams are particularly susceptible to channel changes because of their steep gradients and high potential energy to erode. Where local channel slopes are steep and stream velocities are high, relatively large amounts of energy will be available for channel alterations (Sullivan 1987). As water descends, potential energy is transformed to kinetic energy. Some kinetic energy is utilized for sediment transport, bed scour, and bank erosion, but more than 95% is ultimately consumed as friction along channel margins (Morisawa, 1968). Thus the rougher a headwater stream is, the more kinetic energy is consumed and channel stability increased.

In headwater streams many natural mechanisms exist that allow streams to adjust channel shape, which helps to protect stream beds. These mechanisms include: bed armoring by gravel and boulders, gravel bars that form transverse to stream flows, and log steps that incorporate fallen timber and associated debris into the stream bed (Marcus, 1990; Sullivan, 1987; Heede, 1980). Each mechanism diminishes stream energy by increasing frictional forces.

Channel Impacts

If a channel receives significantly more sediment or discharge, its initial morphologic response will be to reduce form roughness to permit increases in flow velocity and bedload transport capacity (Jackson, 1984). Initial reductions in form roughness would cause subsequent adjustments in channel width, depth and slope (Jackson, 1984). Other potential responses include braiding, stream bank failures, and reductions in pool volumes and pool numbers (Grant, 1988). Attention also has been focused on the effects of large woody debris removal on channel morphology following logging. Removal can reduce channel roughness, increase stream energy, and reduce sediment storage behind log steps.

Woody Debris

Large woody debris (LWD) is an important component of salmonid habitat in streams throughout the Pacific Northwest (Bisson et al., 1987). It helps retain organic and inorganic particulate matter that is important for stream stability and biological productivity (Bilby, 1984). Large woody debris also provides structure and hydraulic roughness which can significantly affect habitat for fish and other aquatic organisms (Beschta and Platts, 1986). Low velocity microhabitats created by woody debris can provide temporary refuge during high stream flow, and, during low flow, provide cover and reduce predation (Tschaplinski and Hartman, 1982).

Log Steps

Small headwater streams in forested areas are heavily dependent on the input of organic material from the surrounding terrestrial system (Bilby and Likens, 1980). Small to intermediate channels with large quantities of woody debris have small step-like riffles and abundant plunge pools (Meehan, 1991). Step-like riffles form a series of vertical falls which reduce the potential energy of water (Marston, 1982). By reducing potential energy, sediment is stored behind logs steps with no consequent erosion from the bank or bed (Heede, 1972a). Second-order channels store the largest amounts of sediment per unit area because peak discharges in the second-order channels are not great enough to dislodge most small-debris accumulations (Potts and Anderson, 1990). Bilby (1981) found in New Hampshire that woody debris stored 87 percent of channel sediment, while the cleaning of debris resulted in a 500 percent increase in sediment export the following year.

Fish Habitat

Large woody debris plays a major role in the geomorphology of stream channels; therefore, fish habitat is intricately tied to the dynamics of LWD. Large woody debris provides cover for fish, creates important hydrologic features (such as pools and backwater areas) and stores inorganic sediment. The importance of

LWD to fish populations is recognized in a number of articles (Meehan et al., 1977; Sedell et al., 1982; Bryant, 1983; Bisson and Sedell, 1982). For example, coho biomass in coastal Oregon streams is directly related to pool volume (Sedell, et al., 1988). Angermeier and Karr (1984) found that more species, individual fish and large fish are captured in streams containing debris than in cleared streams.

Most salmonid species use different habitat in winter than in summer. Large, stable, woody debris is important winter habitat for cutthroat, brook, and bull trout. All species prefer pools during base flow, but the level of preference is determined by pool quality and abundance of woody debris (Sedell et al., 1988). Wilzbach observed that salmonids prefer to hide in cracks and crevices at temperatures less than 5°C, but found that trout in an open clear-cut reach, with less LWD do not hide in substrate. At very low temperatures (< 2.5°C), trout were observed hiding under logs and roots (Sedell et al., 1984). If woody debris is removed or altered, winter cover may be reduced, decreasing trout populations.

Harvest Impacts

Among the most important long-term effects of forest management on fish habitat are changes in the distribution and abundance of large woody debris in streams (Meehan, 1991). Overall changes include reductions in the frequency of pieces of large stable debris in streams, concentration of debris in large but infrequent accumulations, and loss of important sources of new woody material for stream channels (Bisson et al., 1987).

Removal of large trees from riparian zones can cause long-term reduction in the recruitment of new large woody debris to stream channels. A short term increase in debris caused by entry of slash may enhance aquatic habitat for a short time, but often the small debris floats downstream within a few years. If debris loads are not replenished by large-scale inputs such as extensive blowdowns or debris avalanches, second-growth riparian vegetation will be the principal sources of new woody debris (Meehan, 1991). Many streams in second-growth forests have become progressively debris-impoverished following logging to the channel's edge (Meehan, 1991). Young riparian stands produce insufficient debris of the proper size and quality to replace logged material (Sedell et al., 1984). The effect on fish habitat is a decrease in channel complexity, stemming from a reduction in number and volume of pools, in quality of cover, and in capacity of streams to store and process organic matter (Meehan, 1991).

Logging debris itself can destabilize stream channels. Bryant (1983) indicated that logged streams contain debris volumes seven times that of undisturbed streams. Because logging debris is more densely concentrated than most natural accumulations, it can severely constrict flow (Bryant, 1983). The result may be rapid stream bed and stream bank cutting from deflected flows.

As mentioned earlier, large woody debris plays a key role in shaping channel morphology and retaining sediment, particularly in small, high gradient streams. If large woody debris is removed, pool areas can be reduced and trapped sediments released. Murphy and Hall (1981) found that old-growth streams have more pools with greater structural complexity than logged streams. Sedell et al. (1988) also concluded that stable debris declines and unstable debris increases in logged streams. As a result pool size decreases due to reductions in the number of plunge pools and riffles size increases. Numbers of pools and riffles per unit of stream length decline suggesting that debris removal causes the stairstep profile to be reduced. This increased sediment by removal of storage sites.

Stream Temperature

Changes in stream temperature and light regime after logging can have both positive and negative consequences to salmonids. Under natural conditions, incoming solar radiation is intercepted by stream side vegetation. As a result evaporative and convective transfers of energy are typically low for forested streams because vapor pressure and temperature gradients are smaller and wind speeds lower (Bilby et al., 1987). In contrast, removal of streamside vegetation allows more solar radiation to reach the stream surface, increasing water temperature (Brown and Krygier, 1970). Higher temperatures can kill fish populations by excessive heat, increase metabolic rates and maintenance requirements, increase activities of pathogenic organisms, change pattern of habitat use, and decrease solubility of oxygen in water (Hall and Lantz, 1969).

The causes of stream temperature increases are complex and dependent upon more than just increased solar exposure. For instance, in the tributaries of Carnation Creek, British Columbia, diurnal ranges during the summer increased in proportion to drainage area and stream width (Bilby, et al. 1987). Stream temperature is also dependent upon stream channel characteristics, inflow of surface water and groundwater, and channel area, depth and velocity. (Brown and Krygier, 1967).

For the Pacific Northwest, watershed studies show that mean monthly maximum temperatures increase about 3 to 8°C following clear-cut harvesting (Bilby, et al., 1987). Holtby (1988), found that when 41 percent of Carnation Creek was logged stream temperatures increased in all months of the year. If overstory shade is completely removed in small headwater streams mean monthly maximum stream temperatures can increase by more than 15°C (Brown and Krygier, 1970; Gray and Edington, 1969). Yet in other studies (Carnation Creek and Alsea watershed) diurnal increases during summer after complete clear-cutting were less than 3°C (Bilby et al., 1987).

During winter months, exposed streams may experience lower temperatures where there is no canopy to inhibit energy loss. At higher elevations, a reduction in winter stream temperature may cause ice to form earlier which increases the chances of winter freeze-up. Such conditions may reduce hiding cover in gravels if anchor ice formation is extensive. In contrast water temperatures were found in coastal Carnation Creek to be slightly warmer in winter after harvesting (Holtby, 1988). Earlier emergence resulted in a longer period of growth for young salmon.

Habitat Use By Salmonids

The density of trout in streams appears to be determined by the physical environment, especially current velocity and availability of cover (Lewis, 1969). The value of cover is probably related to a fish's security and a photonegative response in trout causes them to seek areas with overhead cover. Cover is defined as any material or condition that provides protection from predators, competitors, or variations in stream flow (Boussu, 1954). Logs, woody debris, overhanging vegetation near the water's surface, large substrate or deep water can all serve as cover.

Cover

During fall, most species in small streams seek habitats that provide greater security (Sullivan et al., 1987). Channels providing diverse cover should provide for larger resident populations. In fact, Wesche and Goertler (1987b) found that more cover is directly related to abundant fish populations. Overhead bank cover is the most important type of cover for brown trout in Wyoming streams (Wesche et al., 1987a). More fish remain in pools having deep water, undercut banks, boulders and woody debris than in pools having less cover (Meehan, 1991).

Depth

Water depth used by salmonids depends on what is available, the quantity and the type of cover present. Fish have preferred depths, but their preferences are modified by needs for suitable velocities, access to food, and security (Meehan, 1991). In smaller mountainous streams young trout and salmon have been seen in water barely deep enough to cover them, yet also in water more than a meter deep (Meehan, 1991). The relation between stream depth and fish abundance needs further research, but it is suspected that abundance depends on the mixture of fish species, size, types and amounts of cover and stream size (Narver, 1972).

Velocity

Velocity is probably the most important factor in determining the amount of suitable space available for rearing salmonids (Chapman, 1966). If velocities are unsuitable, no fish will be present. Natural streams fortunately contain a wide range of velocities and depths suitable for salmonids if stream alteration does not occur. Velocities required and used by salmonids vary with size and sometimes with species (Meehan, 1991). Velocity and depth preferences may also change seasonally. Chisholm et al. (1987), noted that brook trout selected areas of lower velocity (< 15 cm/s) and deeper water (> 30 cm) in winter than in summer, but showed no preference for substrate. Newly emerged fry (20-35 cm) of trout and salmon require velocities of less than 10 cm/s while larger fish (4-18 cm) usually occupy sites with velocities up to 40 cm/s (Chapman, 1966).

Habitat Impacts

Salmonids occupy a wide variety of streams and have varied life histories. Small streams are particularly important. Small streams are responsible for a high proportion of salmonid production and at the same time are a controlling factor of habitat quality downstream (Meehan, 1991). Because smaller streams are intimately associated with their riparian zones and are highly responsive to alterations in the surrounding watershed, effects from harvesting can be severe. Furthermore, effects upon downstream communities can occur for decades after impact, particularly from sediment and discharge.

Studies of logging impacts have not always led to clear results. Hall and Lantz (1969), found that cutthroat trout in the Alsea watershed declined after clear-cutting and slash burning. Others have noted declines because of excessive sedimentation (Platts and Megahan, 1975), less dissolved oxygen and elevated temperature (Brown and Krygier, 1970), and loss of large woody debris, collapsed stream banks and decreased channel stability (Bisson and Sedell, 1982). More recently, Murphy et al. (1986) concluded that for streams in the Oregon Cascade Range, increased food production resulting from canopy removal masked the effects of logging and led to higher trout populations. Elevated levels of algae and invertebrates have also been documented in other Pacific Northwest streams (Aho, 1976; Narver, 1972; Osborn, 1981). These results have led to speculation that temporary increases in productivity can be expected after logging if no major disruption to the stream channel occurs.

Significant Trout Species

The following review is conveys to the reader habitat needs of species found in streams of this study. The information will be used later in the thesis.

Brook Trout (*Salvelinus fontinalis*)

Though brook trout are indigenous to eastern North America, they have been introduced into the waters of many western streams and lakes. As a result, brook trout displaced many native species. Griffith (1972), indicated that smaller brook trout occupy deeper, faster water at pool tailouts than cutthroat trout, while larger brook trout use slower waters near overhead cover at pool sides. Brook trout abundance also increases when woody debris, backwater pools, overhanging vegetation and sediment accumulation are present (Kozel and Hubert, 1989). It is surprising that sediment accumulation does not affect brook trout like other species. Platts (1974), concluded brook trout appear to increase when substrate had higher fine sediment. In fact, brook trout were the only species found in areas of stream channel containing over 70 percent fine sediment (Platts, 1979). The normal range of water temperature found in brook trout habitats is 0-20°C, depending on the season, and preferred temperature range is 10-12°C.

Cutthroat Trout (*Salmo clarki lewisi*)

The cutthroat trout native to central and northern Idaho, western Montana, and southeastern British Columbia is the subspecies referred to as westslope cutthroat trout. Westslope cutthroat populations display one of three life history patterns: 1) fish live their entire lives in small tributary streams, 2) the fish spawn in small tributaries of larger river systems, spend one to four years in the tributary, then migrate downstream into a larger river until mature, and 3) exhibit a similar life history as in 2) but juveniles migrate downstream into lakes until mature (Griffith, 1986).

Westslope cutthroat trout are usually found in cold, infertile waters. Juveniles that winter in small tributary streams enter substrate crevices when water temperatures drop to 4-5°C (Likens and Graham, 1988). The normal temperature range of westslope cutthroat is between 5-13°C (Griffith, 1986).

Young westslope cutthroat trout tend to be evenly distributed along stream margins, in low velocity areas such as pools, and in run habitats (Likens and Graham, 1988). Lateral habitats are characterized by heterogenous substrates, abundant detritus, and structural protection from high discharges (Likens and Graham, 1988). Large cutthroat trout are associated with woody debris, shade-overhangs, or rock cover types (Pratt, 1984). Cutthroat also select areas where water velocity is reduced by stream morphology, including boulder substrates or woody debris, often in complex structures (Pratt, 1984). Cutthroat trout usually frequent in small stream pools and stream margins where water velocities are 0.15 meters per second (mps) to 0.28 mps (Pratt, 1984).

Bull Trout (*Salvelinus confluentus*)

Like cutthroat trout, bull trout exhibit varied life history patterns. In some drainages, bull trout spend their lives in cold headwater streams. In others, they spend the first two to four years in small natal streams and then migrate into larger rivers and lakes where they spend another two to four years before maturing. Bull trout that stay in cold headwater streams their entire lives do not exceed 25 cm in length when mature, whereas those in lakes can weigh as much as 10 kg (Meehan, 1991).

Bull trout prefer water temperatures of 5-12°C in streams of the Upper Flathead River Basin (Pratt, 1984). Bull trout spawn when water temperatures drop below 9-10°C.

Pratt (1984) noted that juvenile bull trout often use a combination of woody debris or rock cover with shade overhang and often use cobble and rubble substrate when in "open" areas. Bull trout use run/riffles more frequently than pools, because more pockets of slow velocity and visual isolation are available along the stream bottom (Pratt, 1984).

Juveniles also differ from other species in that they are usually found closely associated with stream substrate (Fraley and Shepard, 1989). Juvenile bull trout may be at risk if sedimentation increases and causes a shift in substrate composition. In laboratory experiments, survival of embryos was inversely related to the percent of fine material (< 0.35 mm) in gravels (Weaver and White, 1985). Survival to emergence ranged from 50 percent in substrates which contained 15 percent fines to zero percent in mixtures containing 50 percent fines.

DESCRIPTION OF STUDY AREAS

Introduction

The following chapter provides a brief overview on watershed selection criteria, regional climate, watershed geology, vegetation, morphology, and management history. In addition, watershed locations are provided.

Criteria For Site Selection

Twelve watersheds of the Lolo National Forest were selected using air photos (1: 63,360) and a forest map (1: 126,720). Surveyed watersheds (with exception of Sunset Creek) had no past or current placer mining nor any significant grazing withhin the past 70 years. Watershed disturbances were limited to natural events (hillside failures, floods, etc...) and timber harvest to limit variability.

Each watershed was evaluated by comparing basin area, basin orientation, landform type, geology, precipitation, stream order, stream gradient, basin elevational maximum and minimum, and drainage density (Table 1, pg. 32).

Unharvested basins are defined as having 10% or less of their area harvested. Heavily harvested basins have 30% or more of their area harvested in the last 30 years. Moderately harvested basins fall between these values. Table 2 (pg. 33) illustrates activities that occurred within surveyed basins.

Watershed Locations

All watersheds are within the Lolo National Forest which ~~consisting~~ consists of 2.1 million acres in northwestern Montana (Figure 1, pg. 34). Watersheds were selected from an area bounded to the north by the Cabinet Mountains, to the south by the Sapphire and Bitterroot Ranges, and to the west by the Idaho state line. Surveyed watersheds are scattered throughout the forest (Figure 2, pg. 35 and appendix B). Most watersheds are owned by the Forest Service except for Allen, Deer and Bird Creeks where lands are owned by Champion International and Plum Creek Timber.

Climate

The Continental Divide creates a physical barrier which greatly influences the climate of Montana. Areas west of the Divide are dominated by a maritime (North Pacific Coast) climate (Sasich and Lamotte, 1989).

Temperatures in Missoula (elevation 3,150 feet) (960 m) are representative of the forest (Sasich and Lamotte, 1989). Average daily temperatures in Missoula from 1951-1978 ranged from -5.6°C (22°F) in January to 19.6°C (67°F) in July. Extreme temperatures for the same period were -15.5°C (-26°F) to 38.6°C (101°F).

Precipitation ranged from 15 inches (0.38 m) average annually in the Missoula Valley to 100+ inches (2.57m) on mountain peaks around 9,000 feet (2,743 m) of elevation. The northwestern portion of the forest receives the highest amounts of precipitation and the southwestern portion receives the least. Over two-thirds of the precipitation received falls as snow. Nearly half of the average annual 42 inches (1.07 m) of precipitation that falls on the Lolo National Forest's watersheds is released as streamflow (Sasich and Lamotte, 1989)

Geology

The predominant bedrock type in survey areas is the partially metamorphosed, ancient, sedimentary rocks of the Belt Basin Supergroup, known as Belt metasedimentary rocks. The Belt Series crops out over a region of more than 50,000 square miles and attains a thickness of over 40,000 feet (Obradovich and Peterman, 1968). Figure 3 (pg. 36) is a generalized outcrop map for the Belt Series rocks in the Western United States.

Formation of the Belt Series occurred during Precambrian time, when sediments composed of silt, clay, sand, and carbonate material were deposited in an expansive shallow sea (Sasich and Lamotte, 1989). Sediments were compressed and cemented into sedimentary rocks such as sandstones, siltstones, shales, and limestones.

Metasedimentary rocks underlie at least 90% of total basin area in all watersheds except Lupine Creek. The Belt Series contain argillite, calcareous argillite, and some siltite. Soils are slightly plastic loams and silt loams (Sasich and Lamotte, 1989). Soils have a moderately low erodibility and a high water holding capacity. When used as road material, Belt rocks tend to rut when wet.

Within the study basins, alluvial flood plains, terraces, and some break lands are composed of unconsolidated materials derived predominantly from Belt geology.

Dominant Overstory Vegetation

Surveyed watersheds are predominantly covered by coniferous forest species that vary spatially and geographically. Two dominant vegetative regions are present within the study area: mesic/cold conifers and dry conifer/shrubs. The division reflects the presence of a maritime climate north of Superior and Plains and a continental climate south. Maritime watersheds north (Honeymoon, W.F. Thompson, Big Spruce, Fourlakes, Sunset, and Jordan Creeks) have terrestrial and riparian vegetation dominated by western redcedar (Thuja plicata), grand fir (Abies grandis), engelmann spruce (Picea engelmannii), subalpine fir (Abies lasiocarpa) and whitebark pine (Pinus albicaulis).

Continental watersheds (Crystal, Allen, Bird, Fire, Lupine and Deer Creeks) are dominated by ponderosa pine (Pinus ponderosa), western larch (Larix occidentalis), and douglas-fir (Pseudotsuga menziesii).

Fish

Fish species varied between streams in the study area. Most streams contain westslope cutthroat trout (Salmo clarki), while only Lupine, Deer, and Bird Creeks support brook trout (Salvelinus fontinalis). Bull trout (Salvelinus confluentus) were found only Spruce and W.F. Thompson Rivers.

Management History

Fire

Until the early 1900's, most watersheds experienced little disturbance except from floods and fires. Periodic wildfires would often burn large areas creating a patchwork pattern of successional stages. One such fire in 1910 burned over three million acres in Idaho and western Montana including most watersheds within this study. Because of their cooler, wetter, north-facing slopes, only those study basins near Thompson Falls escaped unscathed (Losenski; personnel communication). This is due to cooler, north facing slopes that held wetter vegetation.

Timber Harvest

Timber resources in western Montana have been used to some extent by Native Americans for hundreds of years, but it has only been within the last 100 years that extensive harvesting has taken place. At first, timber was harvested from accessible valleys and riparian areas, but within 30 years stands were depleted of prime timber. This caused operations to move to headwater areas with steeper side slopes. By the 1940's most harvesting occurred within headwater basins.

Watersheds of this study were harvested primarily from 1968 to 1975 with some additional harvesting occurring in the late 1970's to early 1980's. During this period the Forest Service began to change its harvesting philosophy. Economies motivated the Forest Service to maximize timber yields. Cutting units became larger (from 30-40 acres to 200+ acres) not only to meet higher timber demands but also to provide higher returns on investment dollars used to layout the sales. As a result, many surveyed watersheds contain large cutting units and have more of their total area cut, than watersheds planned in later years. Watersheds cut after 1975, on the Lolo National Forest, were subject to more restrictive environmental reviews.

From 1968 to 1975, jammer roads construction prevailed because it was state of the art at that time. Cable logging was restricted to hauling logs short distances to roadside landing areas; thus, high road densities and tractor logging occurred. It was not until the late 1970s that cable logging improved to the point that fewer roads were needed. Environmental concerns about tractor logging also forced changes. As a result, many managed watersheds of this study have higher road densities than watersheds harvested after 1975.

Table 1. PHYSICAL WATERSHED CHARACTERISTICS WITHIN PAIRED BASINS

STREAM	ACRES	PERCENT BELT GEOLOGY	PRECIPITATION (INCHES)	STREAM ORDER	AVERAGE GRADIENT	DRAINAGE DENSITY (MI/MI^2)
CRYSTAL (U)	3072	95	20-25	2	8.7	10.9
ALLEN (L)	3501	100	20-25	2	6.4	10.1
LUPINE (U)	3827	75	35-45	2	3.8	8.7
DEER (L)	4236	98	35-45	2	9.9	8.1
JORDAN (U)	1626	100	40-50	1	14.9	6.5
SUNSET (L)	1965	97	40-50	1	13.3	7.2
FIRE (U)	3635	97	40-50	3	12.1	6.2
BIRD (L)	4836	90	40-50	3	11.8	7.7
SPRUCE (U)	2324	91	50-70	3	14.9	5.2
FOURLAKES (L)	3318	100	50-60	3	13	4.2
HONEYMOON (U)	4216	96	70-80	3	13	7 7
W.F.THOMPSON (L)	3184	90	80-90	3	9	7.7

Table 2. LOGGING ACTIVITY WITHIN PAIRED BASINS

STREAM	ACRES HARVESTED	% OF BASIN HARVESTED	TIME SINCE HARVEST (YEARS)	ROAD DENSITY (MI/MI^2)	ACRES HARVESTED IN RIPARIAN ZONE
CRYSTAL (U)	26	1	8	0.2	-
ALLEN (L)	1011	29	18	2.5	31.5
LUPINE (U)	-	-	-	-	-
DEER (L)	2243	53	19	6.6	115.9
JORDAN (U)	-	-	-	-	-
SUNSET (L)	371	19	22	5	57.3
FIRE (U)	138	4	4	1	25.5
BIRD (L)	1429	30	19	3.5	102.5
SPRUCE (U)	-	-	-	-	-
FOURLAKES (L)	605	18	27	3.6	170
HONEYMOON (U)	425	10	27	1.2	-
W.F.THOMPSON (L)	694	22	22	4.5	92

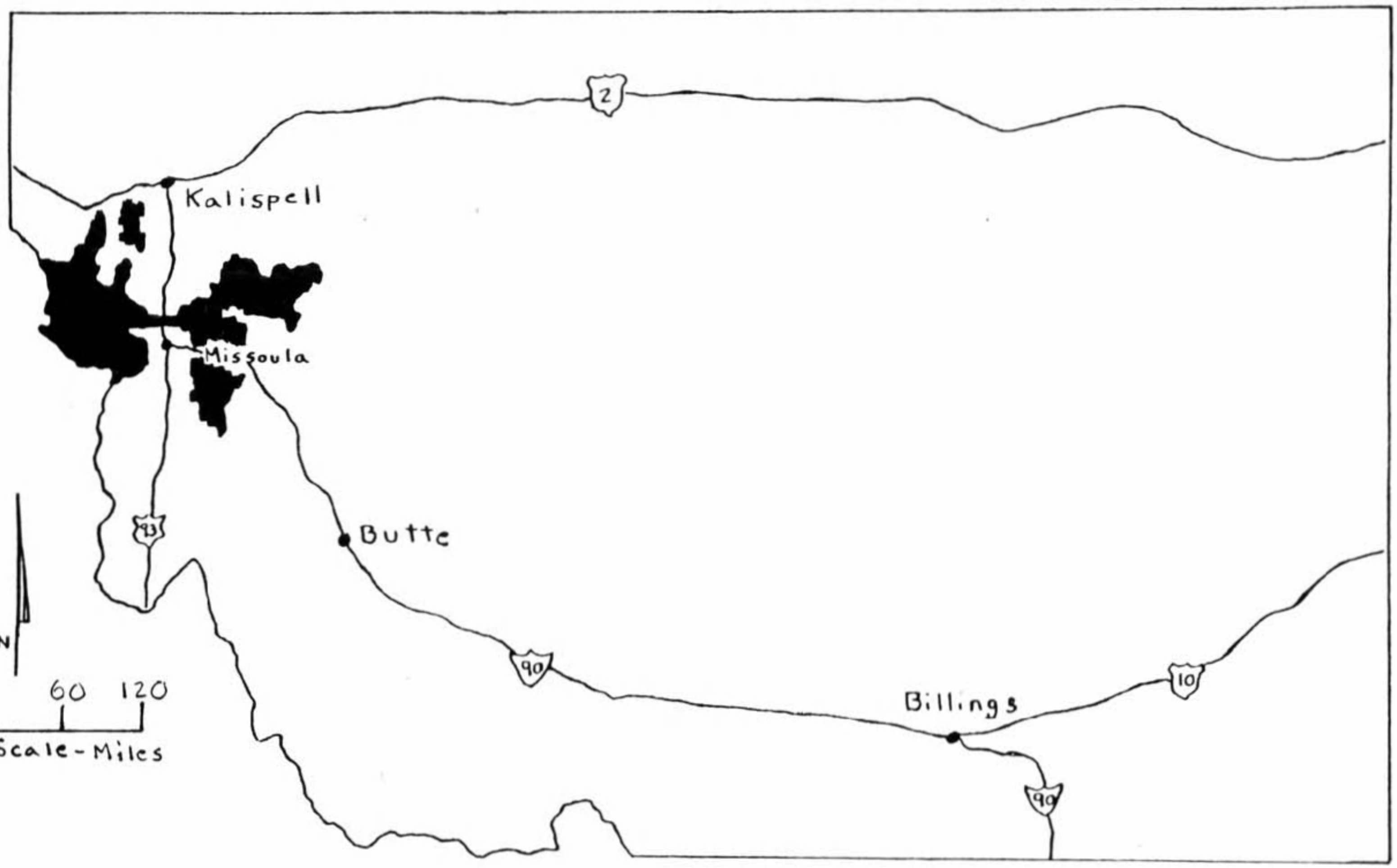

Figure 1. The Lolo National Forest In Relation To Montana

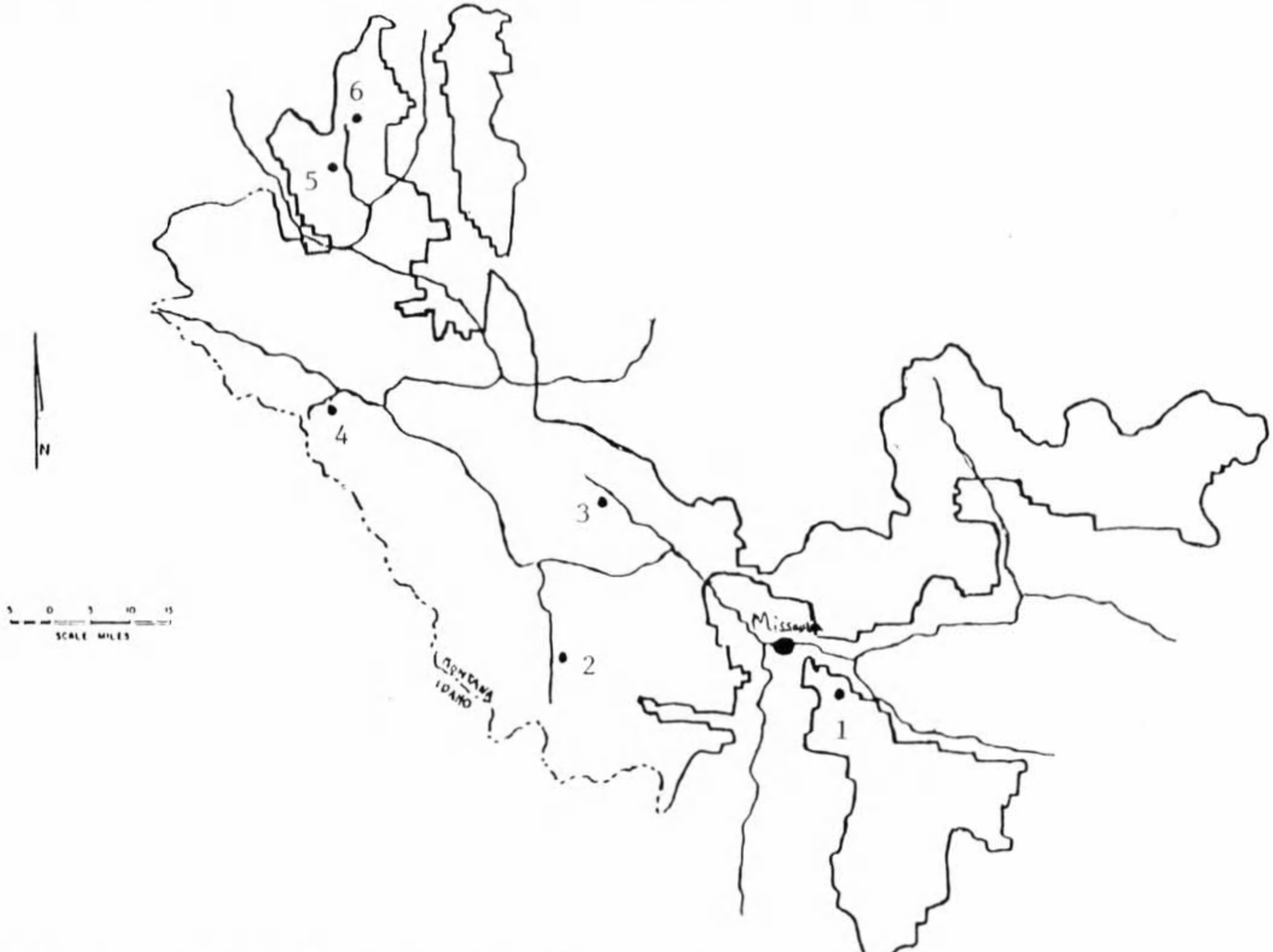

Figure 2. Study Watersheds On The Lolo National Forest
1-Crystal/Allen; 2-Lupine/Deer; 3-Fire/Bird; 4-Jordan/Sunset
5-Honeymoon/Fourlakes; 6-Spruce/W.F. Thompson River

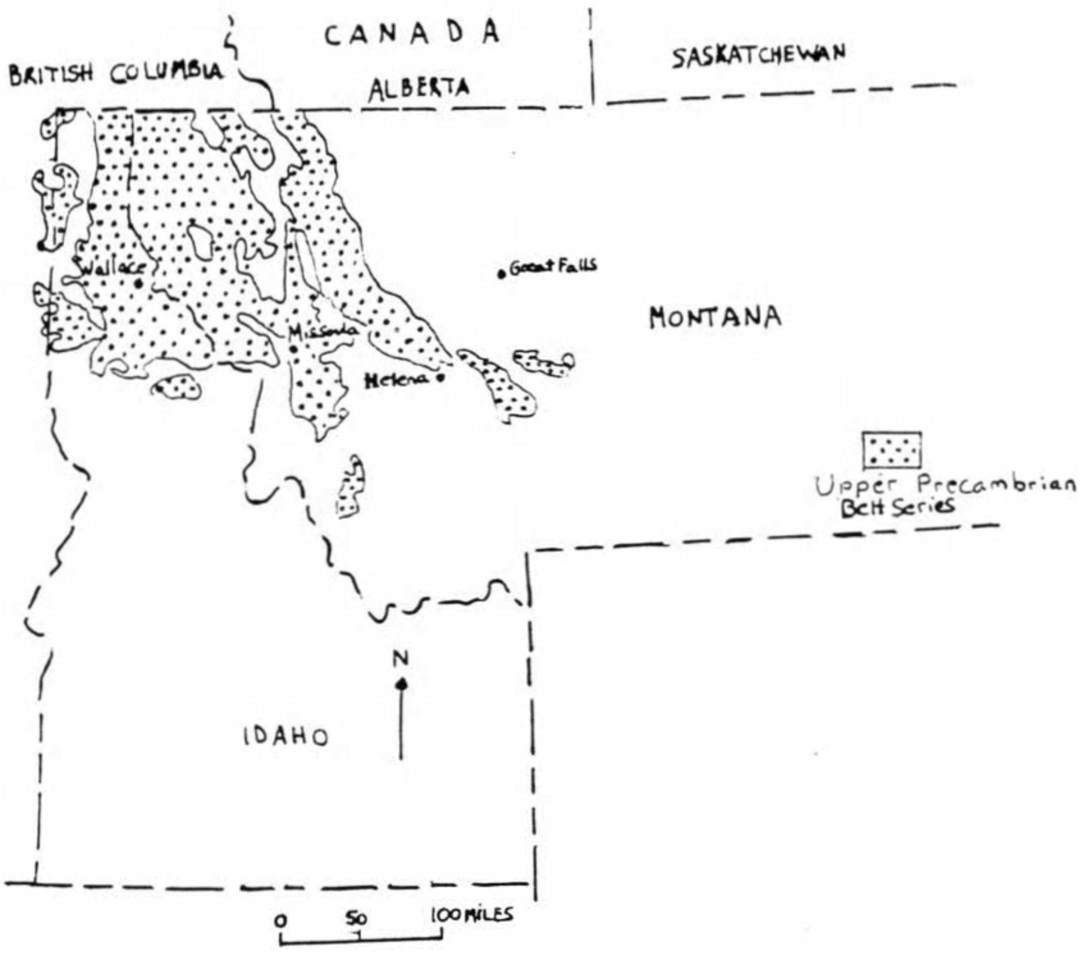

Figure 3 Distribution Of Belt Series Geology
(From Obradovich and Peterman)

METHODS

Study Design

The study design incorporates a paired watershed approach. This involves comparison of drainage basins with similar biophysical characteristics (climate, geology, soils, and morphometry) but different land-use activities. Before it can be concluded that logging has impacted channel morphology and fish habitat, basins with similar biophysical conditions and dissimilar land-use histories must be selected for comparison. Two basins are considered homogenous if climate, geology, soils and basin morphometry are similar. However, no two watersheds can be identical in all aspects. This is why it is important to demonstrate some degree of similarity quantitatively to substantiate conclusions made about treatment effects.

The advantage of paired watersheds is that the control provides a basis for separating the treatment effect from other extraneous factors (i.e. climatic events.) Nevertheless, unless replicated this decision still has serious flaws. Without replicated treated and control sites, no information on the spatial variability of parameters is available. This is why multiple pairs (six pairs) of treated and control streams were selected. Both the control and treated sites are subject to similar extraneous factors, which greatly increases the likelihood of detecting treatment effects (MacDonald, et al. 1991).

Stream Habitat Inventory

Stream inventories used a modified Hankin and Reeves methodology (1988). Visual estimates of stream habitat length, width and area were replaced by tape measurements to provide for greater accuracy. Since stream habitat was measured, the calibration ratio to correct for visual bias (Hankin and Reeves, 1988) was not used.

Streams were divided into reaches so that data were homogeneous. This allowed comparison of reaches having similar physical characteristics (gradient, etc.). Termination of reaches occurred at the entrance of tributaries which contributed >10% stream flow to the main channel (determined occularly), at gradient changes >2%, at channel alterations caused by management activity, or at 800 meter intervals along homogenous sections of stream. All reaches were recorded on 1:24,000 USGS topographic maps. Stream gradient was determined using a clinometer sitting 30 meters upstream and recorded several times within each reach.

I collected data by identifying a habitat type, and then measuring its length and width using a 30 meter tape. Several widths (bank to bank at low flow) were taken along each habitat unit and an average width was recorded. Average and maximum depth were measured, using a meter staff, to the nearest centimeter, at numerous locations across the channel.

Additional habitat characteristics were recorded at greater intervals. A systematic sample of the surveyed habitat was taken by intensively measuring ten percent of all habitat units. Random numbers were selected before surveys began on each stream. For example, if the number selected was 7, then under a 10% systematic sample, intensive measurements would be taken every seventh, seventeenth and twenty-seventh habitat unit. By intensively measuring 10%, inferences on remaining habitat conditions could be made.

Habitat Classification

Habitat type was used to partition a stream into similar physical units that have been shown to be important to fish. Basic habitat types were: pool, riffle and run (or glide). More detailed habitat classifications followed those defined in the "Glossary of Stream Habitat Terms" (Habitat Inventory Committee, Western Division of the American Fisheries Society, 1985). Pool types included: backwater, trench, plunge, lateral scour, dammed, alcove, corner, and underscour pools. Riffle types included: secondary channel, low gradient bedrock, low gradient gravel, low gradient cobble, low gradient boulder, rapids, and cascades.

Structural associations of pools included: boulder, large wood debris, enhancement structure, beaver dam, culvert, falls, streambend, rootwad, and gravel bars. Pocket water was associated with riffle habitat.

Because consistent identification of habitat units was vital to the success of the survey, I personally identified all habitat units in every stream.

Bank Condition

Eroding banks and overhead cover were used to gauge bank condition. Both variables were measured only on intensively surveyed habitats. The total length of eroding banks and of overhead cover were recorded to the nearest 0.5 meter. Overhead cover is defined as an undercut bank having an overhang of at least 7.5 cm and at least a 15 cm water depth under the overhang (Wesche, 1987b).

Riparian Condition

Four variables determine riparian condition: overhanging vegetation, canopy density, successional stage, and dominant vegetation. Overhanging vegetation was measured on intensive habitat units by recording the total length along both banks. Only vegetation available as cover (within 30 cm of the water surface) was recorded.

Percent canopy density was determined with a spherical canopy densiometer. A densiometer is a concave mirror divided into 24 squares in which overhead vegetation can be measured. Because the densiometer has a concave reflecting surface, an overlap of lateral and overhead vegetation occurs. To account for this bias, only 17 of the 24 squares were used. A right angle V was taped on the mirror's surface (Figure 4, pg. 47), which reduced areas that reflected both lateral and overhead vegetation. Canopy density was estimated by counting the number of points (line grid intersects) that were intercepted by vegetation within the V-outlined area (maximum of 17 points). Four readings were taken from the middle of the stream facing upstream, left bank, downstream and right bank. If a habitat unit was longer than 100 meters, multiple readings every 100 meters were taken and an average recorded. Canopy density was recorded only on intensive habitat units.

Successional stage further identified the structure and age composition of the riparian zone. Occular measurements of riparian stands determined successional stage. Riparian overstory was classified into 7 possible successional stages: seedling (3-10 yrs), sapling (10-40 yrs), pole (40-70 yrs), immature (70-120 yrs), mature (120-160 yrs), overmature (>160 yrs) and non-stocked (<300 trees/acre and <10% crown cover). Successional stage was recorded only on intensive habitat units.

A dominant upper and lower riparian composition classification was used following 1990 Nez Perce National Forest Basin Wide Survey Methodologies (U.S.F.S., 1991a). Vegetation for each intensive habitat unit was defined according to categories that reflected conifer and shrub dominance. Upper layer categories included: mesic conifer, cold conifer, dry conifer, broadleaf deciduous trees, dry shrub and moist shrub. Lower layer categories included: dry shrub, moist shrub, dwarf shrub, tree seedling or sapling, grasses, forbs, and ferns (for a detailed explanation of each category refer to appendix A). Each category contained species selected to guide category placement. Vegetation was sampled in areas influenced by high water tables, as well as upland areas within 30 meters of the stream channel.

Large Woody Debris

Woody debris was measured in two ways. First, all in-channel woody debris was counted and placed into an active or inactive debris category. Active woody debris must provide overhead cover, stability, and long-term habitat and be over 10 cm in diameter and greater than 1 meter long. Inactive woody debris has diameters of at least 10 cm and lengths of 1 meter, be stable within the channel, but at the present time provide no instream cover or habitat. Second, a ten percent subsample collected woody debris length, diameter and position data. The length and diameter of every tenth piece (active or inactive) was measured to the nearest centimeter. Large woody debris position was classified according to the log's structural role in the stream channel. Four categories: bridge, collapsed bridge, ramp and drift (Appendix A) were recorded.

Potential woody debris consisted of trees that potentially could enter a stream channel and remain to provide, instream cover. Visual counts recorded all standing trees on both banks in intensive habitat units. Only trees with a large enough diameter at breast height (DBH) to create instream cover were recorded. A DBH of 30.0 cm was required to provide a minimum diameter capable of withstanding high stream flows and remaining within the stream channel for an extended period of time.

Substrate Composition

A particle size distribution was obtained by a procedure termed a "Wolman Pebble Count" (Leopold et al, 1964) which involved samples of 100 pebbles. Pebbles were haphazardly selected on all intensive habitat units by reaching down with eyes closed and measuring the substrate encountered. Samples were distributed evenly throughout all intensive habitat units and tallied by diameter classes using a handcounter. Diameter classes included: bedrock, boulder >30.5 cm, large rubble 30.5 cm-15.2 cm, small rubble 15.2-7.6 cm, coarse gravel 7.6-2.5 cm, small gravel 2.5-.6 cm, and sand/silt <.6 cm (size classes used in fishery studies by forests in Region 1).

Stream Temperature

During the first field season max/min thermometers were used to record water temperature. Thermometers were placed in shaded sections of stream and sampled on a biweekly interval from mid-June till October 1st. Maximum and minimum temperatures were recorded.

During the second field season, max/min Thermometers and Peabody-Ryan (model J) Thermographs monitored water temperature. Max/min thermometers were placed in streams close to Missoula, while thermographs were placed in streams in the Thompson Falls area. Maximum and minimum temperatures were recorded biweekly on streams containing max/min thermometers, and monthly (using continuous data) for streams in Thompson Falls area.

Basin Analysis

Two methods documented management activities; 1) road encroachment and 2) "WATSED" water/sediment model (U.S.F.S., 1992). Road encroachment was measured on each bank on intensive habitat units. Encroachment was recorded if the roads prism was less than 30 meters from the stream and measurements placed into three categories: low (10-30m), medium (5-10m) and high (<5m).

"WATSED" calculated increases in sediment , average discharge and peak monthly discharge. Data on watershed size, elevation, precipitation, land type, and management history (roads, harvest, fire, etc.) were taken using land system inventory (LSI) maps, topographic maps, timber stand compartment maps, timber harvest data bases and airphotos. A management history was then utilized as a comparison between harvested and non-harvested basins. Increased sediment and discharge calculated by "WATSED" provided rough comparisons. Sufficient data has not been collected to correlate monitored suspended/bedload sediment with model-generated estimates. WATSED output serves only as an index of watershed disturbance and does not predict specific types of channel disturbance. For example, WATSED will estimate increases in sediment above natural levels caused by logging, but it will not determine how this sediment impacts substrate composition or how it is stored within the channel.

Statistical Analysis

Analysis was preformed using the statistical package Data Desk (Odesta Corporation) and Harvard Graphics. Data were summarized and displayed graphically to look for influential outliers that could limit the use of parametric tests. Habitat length, woody debris diameter and woody debris length were found to have non-normal distributions and were log transformed.

Continuous (numeric) data were analyzed using a two-sample t-test (variances not assumed equal) and paired t-test to investigate differences between variable means in logged/unlogged basins. A null hypothesis that the two population means were equal (H_o: $\mu_1=\mu_2$) was tested against (H_a: $\mu_1\neq\mu_2$) at an alpha level of 0.05. Discrete (categorical) data were analyzed using a Chi square test at an alpha level of 0.05 (H_o: Column proportions are equal). For each cell, a standardized residual was calculated to describe the extent to which observed counts differed from expected counts. The residuals were then added to produce the chi-square value. Therefore, the largest residuals would give an indication which category or cell in the table influenced the total chi-square value. From this comparisons could be made between similar inflated values of logged or unlogged watersheds. Residuals were considered high if above ± 1.00.

Simpson's Index (appendix A) was used to measure diversity in categorical data. A larger Simpson's value would indicate a high level of diversity. Logged basins could be compared to determine if management consistently caused lower or higher diversity in categorical data.

Regressions and Pearson product-moment correlations were also used to investigate linear relationships between select variables. For example, channel gradients were compared to stream depths and active woody debris. Regressions and correlations were first made on a per pair basis using individual observations, then made using a variable's average for each stream. Twelve points (one representing each stream) were used to look for more generalized trends between logged and unlogged basins.

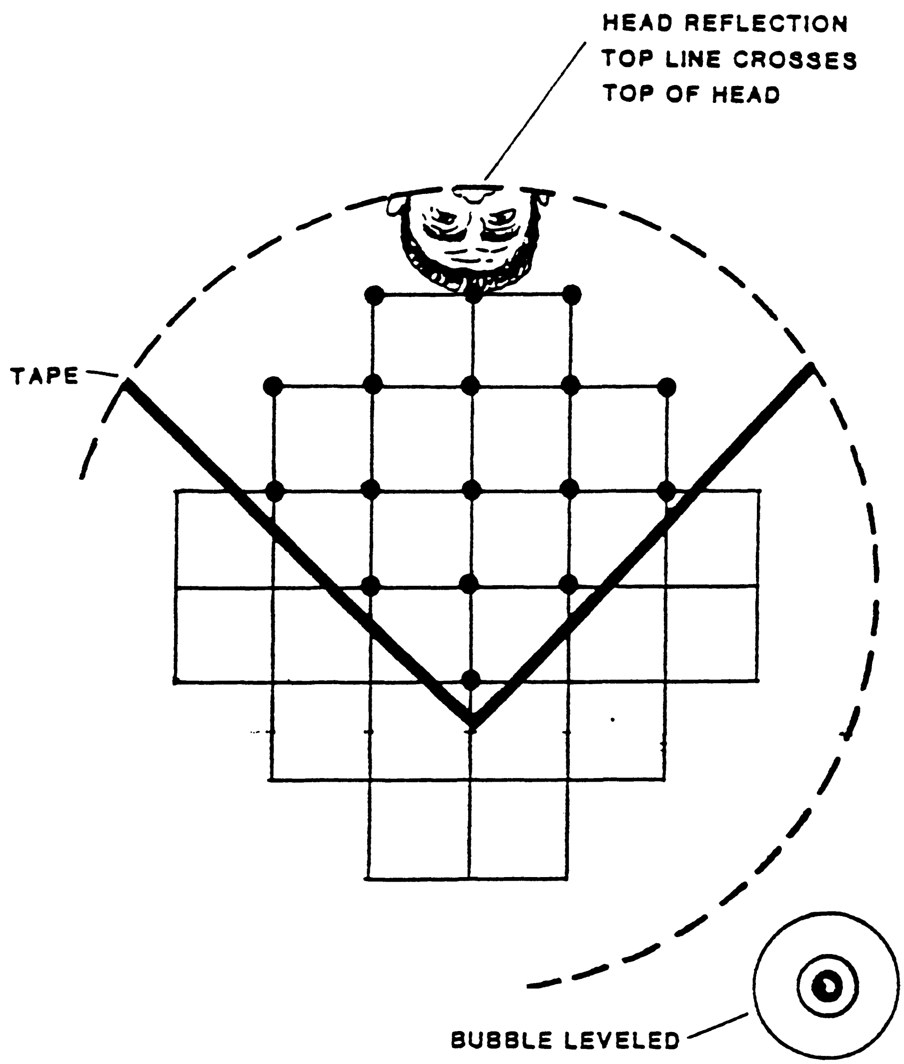

Figure 4. The concave spherical densiometer with placement of head reflection, bubble level, tape, and 17 points of observation.

RESULTS

Section 1

Statistical Patterns of Structural Association, Habitat, and Unit Types

Structural Association

In the summers of 1990 and 1991, I classified 1505 habitat units into descriptive categories. Of these, 674 pools were categorized according to dominant structural association. Chi-square analysis showed that only one of six pairs held significantly different pool types ($P<0.05$) (Table 3, pg. 52). Residual analysis of the significant pair reveals that pools associated with woody debris and culverts are more prevalent in W.F. Thompson River (L=logged) than Honeymoon Creek (U=unlogged).

Residual analysis of non-significant pairs indicate no specific trends. Streams, while overall very similar in pool structural association, tend to be very individualistic. For example, Lupine Creek (U) contains more gravel bar and streambend formed pools than its logged counterpart Deer Creek; Crystal Creek (U) has more gravel-bar-formed pools than Allen Creek (L); and Fourlakes Creek (L) contains fewer pools formed by woody debris than Spruce Creek (U).

Analysis of structural association was also attempted using the Simpson's Diversity Index (Appendix A). Logged watersheds have slightly lower diversity of structural types (0.57) compared to unlogged watersheds (0.65). However comparison within pairs indicates no specific pattern. Streams with significant riparian disturbance (W. F. Thompson River, Fourlakes, Deer) and streams with little riparian disturbance (Allen, Bird) both have similar structural diversities to their controls.

Habitat Types

Only two pairs differ significantly when overall habitat compositions (pools, riffles and glides) are compared (Table 3, pg. 52). Bird and Sunset Creeks have fewer pools and more riffles than their unlogged counterparts. Analysis of non-significant pairs indicates that only Deer Creek (L) has fewer pools than its control. All other streams have equal proportions of habitat types.

Unit Types

Riffle types differ significantly in all six pairs, while pool types were significantly different in only two pairs (Table 3, pg. 52). Residuals of riffle types show no discernible pattern between logged and unlogged basins. Four of six logged basins (Allen, Deer, Bird, and Sunset) have more cascades and one (W.F. Thompson River) holds fewer cascades than their control streams. Other riffle types follow a similar pattern making possible shifts in riffle composition difficult to interpret.

Residuals of pool types indicate no particular pattern within pairs. Two logged basins contain more plunge pools than their controls, one fewer than its control, and three show no difference. Variability between other pool types is also great. For example, some logged basins hold fewer trench pools, others more, and still others none at all.

Structural Association and Unit Types Trends

Gradient, availability of material (wood, boulder, etc) and channel width are are dominant factors in determining pool structural association. Figure 5 (pg. 53) reveals that lower gradient channels (0-5%) tend to have more structural controls than higher gradient channels (5 types compared to 2). In addition to woody debris and boulders, gravel bars, streambends and rootwads are important components at low gradients. At gradients above 5.0%, pool structure is almost always controlled by woody debris or boulders. However, dominance of either structural type varies from stream to stream. For example, Crystal (U), Bird (L), Spruce (U) and Honeymoon Creeks (U) tend to have pools dominated by boulders at gradients above 12.5%. Alternatively, Allen (L), Jordan (U), Fire (U) and the W.F. Thompson River (L) tend to have more woody debris pools above this gradient.

Unit types also vary with gradient. Figure 6 (pg. 54) shows that cascades predominate at gradients above 12.5%. At lower gradients, cascades are infrequent and most riffles are composed of small gravels or cobbles. At middle gradients (5-12.5%), gravel riffles become infrequent and cobble/cascade riffles predominate. Many streams show clear transitions of riffle types as gradient increases. In Bird Creek (L), gravel riffles constitute 51% and cobble riffles 49% of all riffle types at gradients below 5.0%; at 5.0-12.5% gradients, cobble riffles constitute 37% and cascades 63%, and above 12.5% gradient only cascades occurred. Jordan (U), Deer (L), W.F. Thompson River (L), and Fire Creek (U) show similar riffle successions. Streams with gradients above 12.5% had no such succession.

At gradients above 5.0%, dominant pool types are plunge and dammed, but below 5.0% other pool types become more prominent (Figure 7, pg. 55). For example, low gradient reaches in Crystal Creek (U) have trench and lateral scour pools, in Lupine (U) and Deer (L) Creeks corner and backwater pools dominate, and in the W.F. Thompson River (L) lateral scour pools prevail.

Overall, plunge and dammed pools compose no less than 70% of all pool types (Table 4, pg. 56). Because pools occur only at low gradients. Lupine and Deer Creeks have more (55%) corner or trench pools. Plunge pools comprise but 12% of pool types in Lupine and 33% in Deer.

Table 3. SIGNIFICANT CHI-SQUARE VALUES FOR HABITAT PARAMETERS

PAIR	HABITAT TYPES	POOL TYPES	RIFFLE TYPES	STRUCTURAL ASSOCIATION
CRYSTAL/ALLEN	-	-	**	-
LUPINE/DEER	-	-	**	-
JORDAN/SUNSET	*	-	***	-
FIRE/BIRD	**	**	***	-
HONEYMOON/W.F.THOMPSON	-	-	***	*
SPRUCE/FOURLAKES	-	-	**	-

*=SIGNIFICANT(P=0.05) **=VERY SIGNIFICANT(P=0.01) ***=HIGHLY SIGNIFICANT (P=0.001)

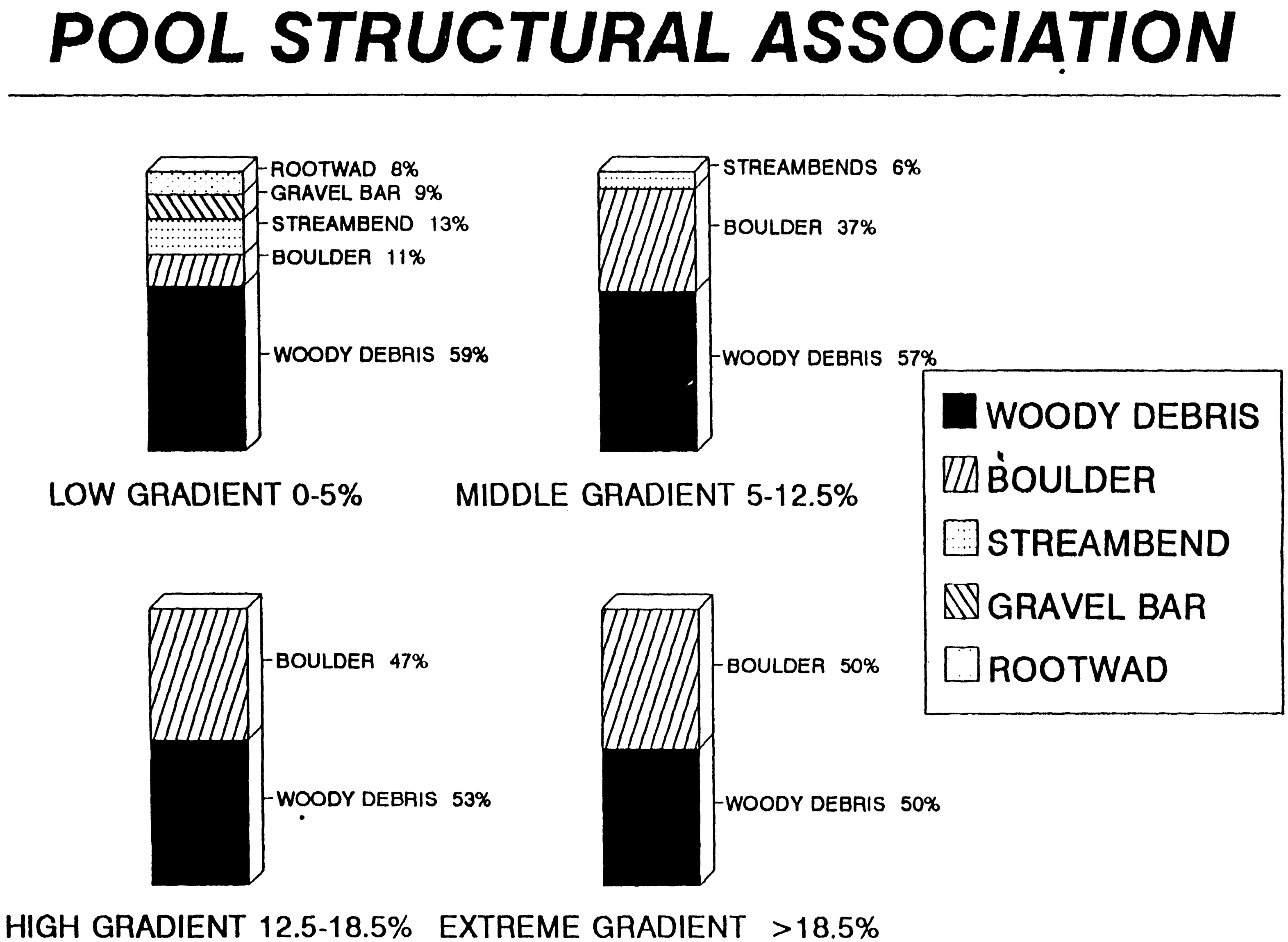

Figure 5. Pool structural association relative to stream channel gradient

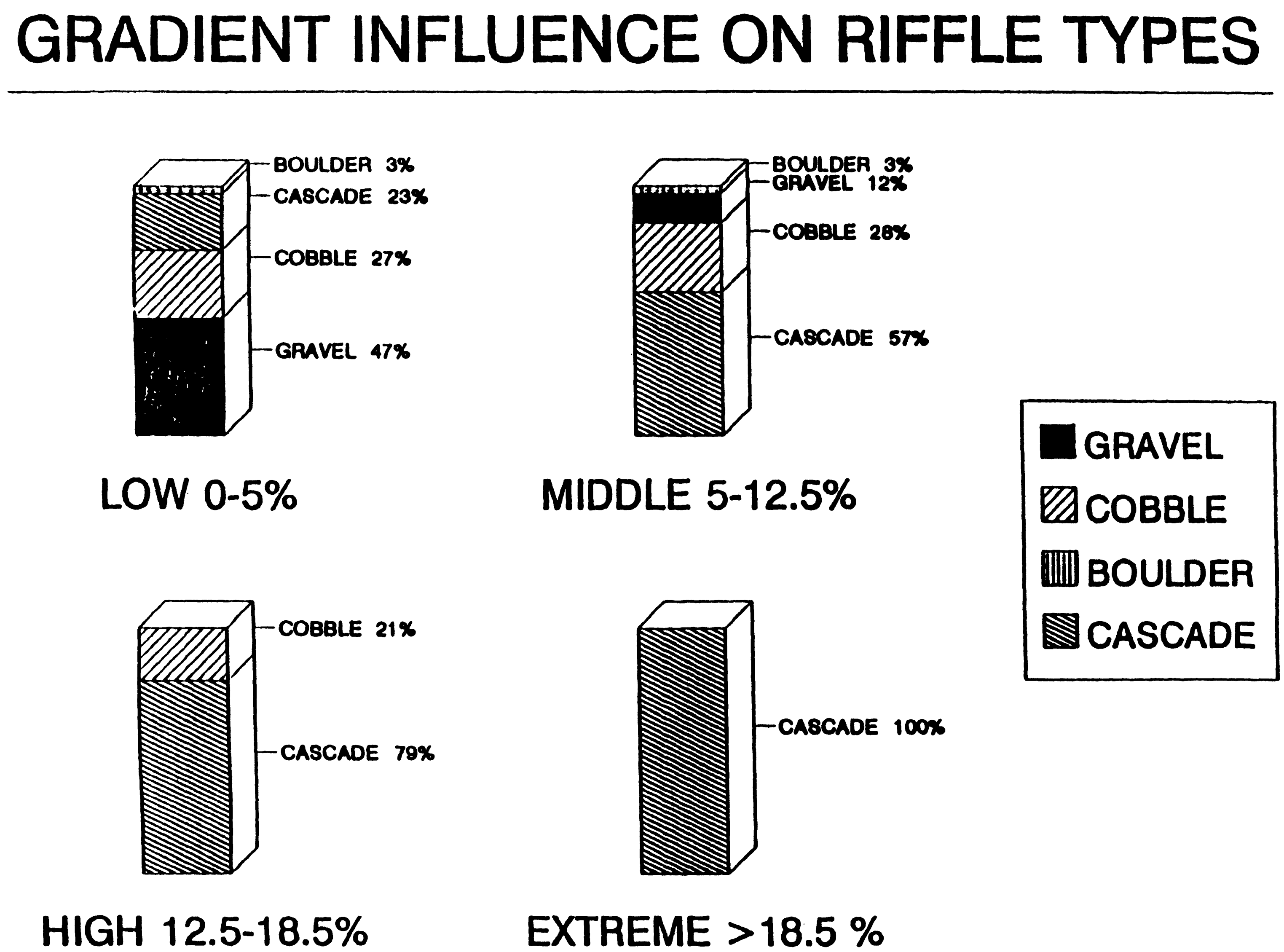

Figure 6. Riffle types in relation to stream channel gradient.

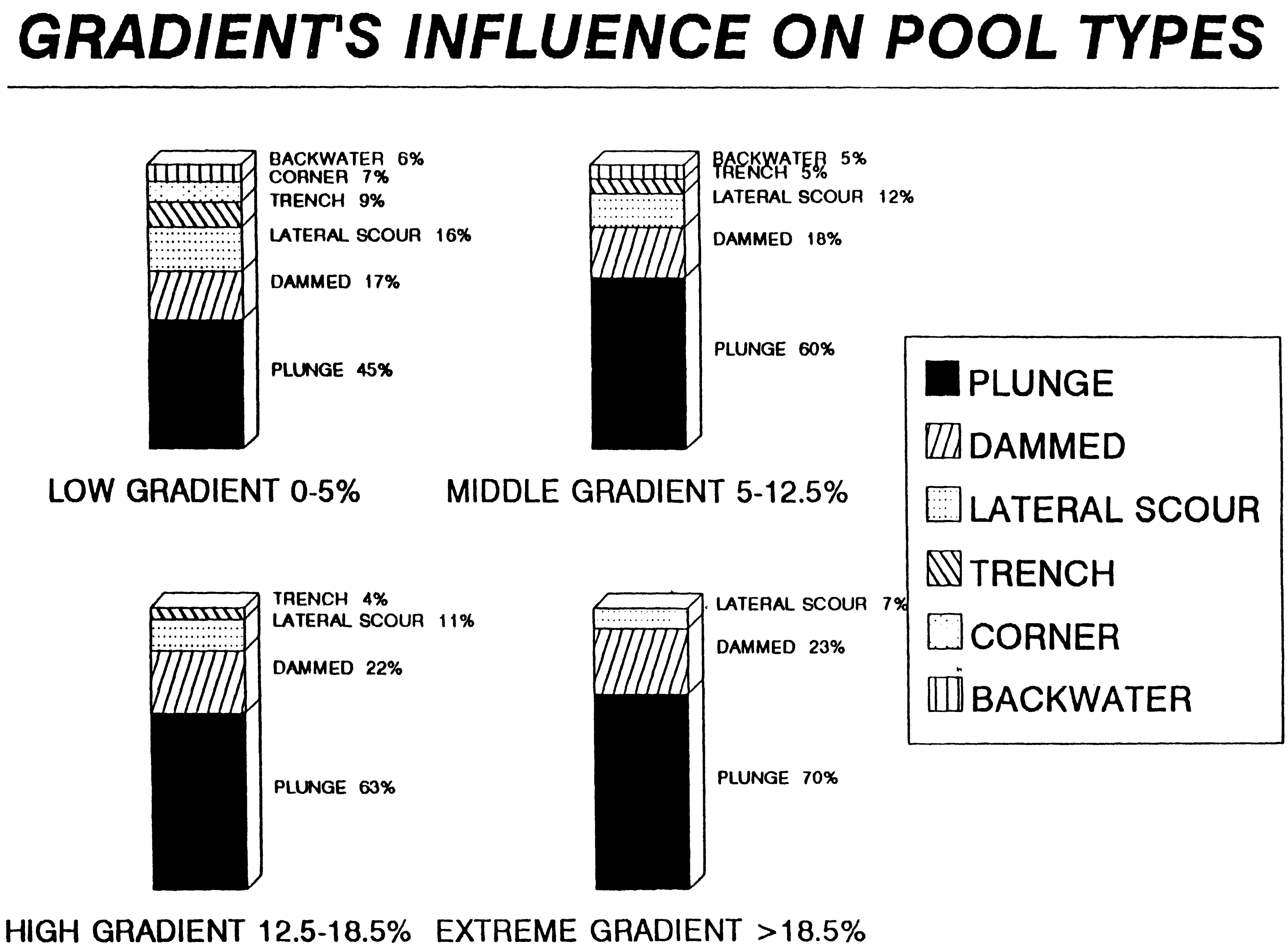

Figure 7. Pool types in reation to stream channel gradient

Table 4. POOL HABITAT TYPES IN LOGGED AND UNLOGGED BASINS

STREAM	BACKWATER	TRENCH	PLUNGE	LATERAL SCOUR	DAMMED	CORNER	UNDERSCOUR
CRYSTAL	10	13	56	8	13	-	-
ALLEN	-	3	78	2	17	-	-
LUPINE	18	18	12	-	4	39	9
DEER	-	17	33	8	-	42	-
JORDAN	3	4	79	14	-	-	-
SUNSET	-	9	78	9	4		-
FIRE	2	5	61	16	16	-	-
BIRD	3	5	39	16	32	-	5
SPRUCE	-	-	75	15	20	-	-
FOURLAKES	6	-	64	13	17	-	-
HONEYMOON	-	7	65	8	20	-	-
W.F.THOMPSON	6	7	62	7	18	-	-

Section 2

Statistical Patterns of Large Woody Debris

To simplify LWD findings, results are reported in several parts: debris loading, active/inactive, potential, diameters, lengths and formation.

LWD Loading

Active and inactive debris were combined to form a total LWD category. Totals were based upon 100 meter sections of channel and compared. Debris loading differs significantly in three of six pairs (Table 5, pg. 68). Two streams within logged basins contain more LWD (Deer and Bird) then their controls, and one (Fourlakes) less, making it difficult to conclude that streams in logged basins carry more debris.

Table 6 (pg. 69) reveals that debris densities are similar within most pairs, except for Deer Creek and W.F. Thompson River. Harvested basins average 20.8 (standard error, 11.0) pieces of debris per 100 meters compared to 16.5 (standard error, 7.2) per 100 meters for unharvested basins. Most surveyed streams, regardless of harvest activity, average 0-30 pieces of debris per 100 meters (Table 7, pg. 70). In fact, 82.0% of reaches in harvested basins and 88.0% of reaches in unharvested basins fall within this range. Some streams do appear to carry extreme levels of debris. Ten percent of reaches in logged basins hold 40-70+ pieces per 100 meters, whereas only 1.3% of reaches in unlogged basins hold this level.

Active/Inactive LWD

Paired t-tests showed that harvested basins hold more active debris per 100m ($P<0.05$) and similar amounts of inactive debris per 100m ($P=0.90$) when compared to unharvested basins. Streams with harvest activity average 1 to 7.2 more active pieces/100m than their control streams.

Many harvested basins retain less inactive debris than unharvested basins (Fourlakes, Sunset, Allen, W. F. Thompson). Three streams, Crystal, Spruce and Jordan Creeks each contain 3-4 more inactive pieces per 100m than their logged counterparts. In contrast, Deer (L) has 7 more pieces of inactive pieces per 100m than its control and Bird (L) has 3 more pieces/100m.

Inactive and active debris are not significantly correlated with the percent of the riparian zone impacted. Riparian harvesting took place in all managed streams; however, three harvested basins (Allen, Sunset and Fourlakes) have less active debris than their unlogged counterparts. Deer, Bird and W.F. Thompson are the only harvested basins with greater amounts of active debris (19-20/100m more).

Potential LWD

Harvested basins contain less potential debris (17 trees/100m fewer) than unharvested basins (paired t-test, $P=0.05$). Two sample t-tests identified four streams with significantly less potential debris (Table 8, pg. 71). Deer, Fourlakes and the W.F. Thompson River each have extensive riparian harvests (Table 9, pg. 72) resulting in less potential debris. However, not all streams follow this pattern. Allen Creek has very little of its riparian zone disturbed, yet still holds far fewer potential trees than its control (18.6/100m fewer). Therefore, it is quite possible that other influences, in addition to riparian harvest, determine potential debris densities.

Figure 8 (pg. 74) shows that, in most circumstances, higher levels of riparian harvest lead to less potential debris. Fourlakes, Deer and W.F. Thompson River each had over 60% of riparian area harvested resulting in 0-29 pieces of potential debris per 100 meters. Bird and Sunset Creeks were subject to lower levels of riparian disturbance and the effect on potential debris is insignificant. Riparian harvests in both streams are limited to first order channels; thus, potential reduction is small for the entire riparian zone.

Figure 9 (pg. 75) indicates that most harvested riparian stands clump below 29 pieces/100m of potential debris. At the same time only one unlogged riparian stand (Lupine) lies within this range. This reflects Lupine's first few reaches being bordered by meadow with few conifers. Unlogged riparian stands clump near 40-45 potential debris/100m and 60-62 potential debris/100m, both of which are significantly higher than most logged riparian stands.

LWD Diameter

Paired t-tests of LWD diameter showed that no significant difference exists between logged and unlogged basins (P=0.67). Investigation of individual pairs showed that two harvested basins (Sunset and Allen) hold larger diameters (7-9cm) than their controls and two basins (Fourlakes and W.F. Thompson River) hold smaller diameters (5-9cm) than their controls.

A comparison of specific habitat types (pool and riffles) shows that pools in harvested basins hold diameters 8.1 cm smaller than pools in unlogged basins. Bird, Deer, Fourlakes and W.F. Thompson River (all logged) each have pools with smaller diameters than their control streams, while Sunset and Allen (logged) have larger diameter material. LWD in riffles follows a similar pattern, with three logged basins having smaller diameters and two having larger diameters than their controls.

Further investigation was completed by grouping LWD into specific size classes (7-15cm, 16-30cm, 31-40cm, 41-50cm, > 50 cm). Chi-square analysis revealed that four of six logged basins were significantly different from their control (Allen, Deer, Fourlakes, W. F. Thompson River). Unfortunately, no definable pattern exists between significant streams. Analysis of residuals for all pairs concluded that most differences occur in 3 diameter classes. Logged basins hold more pieces of LWD over > 50 cm and 31-40 cm, but fewer 7-15 cm pieces. Logged basins also have slightly less diverse ranges of diameter classes (0.63) than unlogged streams (0.70) (Simpson's Diversity Index).

LWD Length

Debris length was not significantly different between logged and unlogged basins (P=0.82). Two sample t-tests of individual pairs found that debris length varies considerably between streams. Two logged basins (Allen and Sunset) have mean lengths significantly longer than their control and two (W.F. Thompson River and Fourlakes) significantly smaller than their control (Table 10, pg. 73). Overall mean lengths, though not statistically significant, were 2.3m shorter in harvested basins than in unharvested.

Both W.F. Thompson River and Fourlakes have pools with shorter debris (2.4m) than their controls. Both streams also have more active debris, less potential debris, smaller debris diameters and smaller debris lengths (2-7m) in riffle habitats. Sunset Creek is the only logged stream having significantly longer debris (8.3m) in riffle habitat. Overall, logged basins have shorter debris (3.6m) in pools but longer debris (3.3m) in riffles.

A dotplot (Figure 10, pg. 75) comparing debris lengths, shows that lengths of 7 to 9 meters in unlogged basins. In contrast, logged basins are more scattered having 3 streams at 7m, two below 6m and 1 above 12m in length. The plot further emphasizes those streams with outlier values (Crystal, Fourlakes, W.F. Thompson River and Sunset). Two values (Fourlakes and W.F. Thompson River) may be attributed to riparian logging, but the others appear to reflect natural variation.

LWD Formation

Debris formation was significantly different in four pairs (Table 11, pg. 76). Interpretation of general patterns is difficult because similarities between formation categories in significant streams are rare. For example, three logged basins (Sunset, Fourlakes, and W.F. Thompson River) contain fewer bridged pieces than their control, while other basins (Bird and Allen) hold more.

Because formation differences within pairs were unclear, debris formation was grouped into two new categories which examined stability. One category, stable debris, has less water contact (bridges, ramped) reducing the chance of movement by flow. The other category, unstable debris (drift, collapsed bridged) has more water contact.

Chi-square analysis of formation stability found that four logged basins (Allen, Deer, Fourlakes and W.F. Thompson River) were significantly different from their controls. However, analysis provided no clear indication that LWD is more unstable than in unlogged basins. Two logged basins (Allen and Deer) hold significantly more stable debris, and two (Fourlakes and W.F. Thompson River) hold less than their controls. A channel width/LWD length proportion (average channel width divided by LWD length) indicated that both Fourlakes and W. F. Thompson River have proportions of 0.91 and 0.76 respectively (value close to 1.00 indicates that LWD length equals channel width and is unstable). In contrast streams in which LWD length exceeds channel width and is stable have proportions of 0.17-0.48. Most small channel streams fall into this range. Overall, streams with larger channels in logged basins hold more unstable material than their control. Therefore, formation was probably more dependent upon channel width then logged residue alone.

LWD Trends

Active/Inactive and Potential LWD

During my analysis I noticed differences between streams with high and low levels of precipitation. Streams with more precipitation (> 40"/year) have larger channels to accommodate higher flows, which in turn influences the amount of active and inactive debris within channel. As a result, I divided streams into four categories: wet logged (Sunset, Bird, Fourlakes and W.F. Thompson River), wet unlogged (Jordan, Fire, Spruce and Honeymoon), dry logged (Allen, Deer) and dry unlogged (Crystal, Lupine).

Results in Table 12 (pg. 78) indicate that high precipitation streams have 8-11 more active pieces and 4-5 more inactive pieces per 100 meters than low precipitation streams. Furthermore, wet logged streams have 3 more pieces of active debris per 100 meters than wet unlogged streams. It became apparent that the larger the channel the more likely LWD is to fall into it. Also high precipitation streams have more potential debris, which increases the chance that LWD would enter the channel.

Active LWD (r = .25) and inactive LWD (r = .50) were not significantly correlated with potential debris in the riparian zone. Nonetheless, analysis indicates that increases in active and inactive LWD occur where potential debris densities are high (Figures 11 and 12, pg. 77). Streams with high potential densities (35-60/100m) have 7-15 pieces of inactive debris per 100 meters. In comparison, streams with (9-30/100m) of potential debris have 2-9 pieces of inactive debris.

High levels of potential debris appear to produce more active LWD in some streams, but in others there is no effect (Figure 11, pg. 77). For example, Spruce (U), Jordan (U), Crystal (U) and Sunset (L) have potential densities of 35-60/100m, whereas Allen (L), Deer (L) and W.F. Thompson River (L) have densities of 9-28/100m. Nevertheless, all streams have active levels of 9-11 pieces/100m.

Figure 13 (pg. 79) indicates that mature riparian forests produce more potential debris than other successional stages. Riparian areas dominated by pole size forests have 4-25 potential debris per 100 meters, while immature/mature forest have 20-67 debris/100m. However the most advanced successional stage does not necessarily produce more active LWD. Mature forest have active debris densities of 5-10 pieces/100m, whereas immature forest have 8-10 pieces/100m. The W.F. Thompson River (L) (non-stocked) is an exception with 20.5 pieces/100m of active debris. This seems due primarily to riparian harvesting which caused an abundance of LWD slash in the low flow channel.

Figure 14 (pg. 80) reveals that streams with cold conifer forests (spruce, lodgepole, subalpine) have 2.6-11.2 pieces of active debris per 100 meters. Streams with dry conifer forest (ponderosa, douglas fir, western larch) have active debris densities of 8.4-9.8/100m and mesic conifer forests (cedar, grandfir) have 10-20.5/100m. Cedar-dominated forests seem to produce more active LWD than other types of forests. A similar pattern occurs for inactive debris, with cold forests having 2.6-3.7/100m, dry forests having 6.8-9.9/100m, and mesic forests having 7.8-14.7/100m (Figure 15, pg. 80).

LWD Diameter

In an attempt to explain natural variation comparisons were made between LWD diameter/LWD length, LWD diameter/average discharge, LWD diameter/dominant riparian overstory and LWD diameter/successional stage. Most variables were not significantly correlated and provided few clear results; however, a few correlations provided insight into factors controlling LWD diameter size.

LWD diameter and length were correlated (Figure 16, pg. 81). Comparison of pairs reveal that logged basins have slightly smaller LWD lengths and diameters. Most unlogged basins (Jordan, Fire, Lupine, Spruce and Honeymoon) have LWD lengths above 7m and diameters above 26cm. At the same time logged basins have LWD lengths of 5 to 7m and diameters 23-29cm (with the exception of Sunset Creek).

Streams with dry conifer forests (i.e. ponderosa, douglas fir, western larch) contain LWD with 20-25cm diameters, and streams with mesic conifer forests (cedar, hemlock) have LWD with diameters of 24-36cm (Figure 17, pg. 82). Streams with cold conifer forests (i.e. spruce, lodgepole, subalpine fir) contain LWD diameters between 27-30cm.

Comparison of diameter sizes and successional stages proved more difficult to interpret (Figure 18, pg. 82). Riparian harvesting shifted some successional stages to non-stocked or pole-dominated forests. Nevertheless, even at this yonger stage, LWD diameters are similar to three of immature/mature forests. Since streams were not cleaned of LWD, diameter size may not have changed significantly. However, as instream material decays, earlier successional stages may not replenish material of suitable size.

LWD Length

Wood lengths are quite similar regardless of changes in dominant overstory species (Figure 19, pg. 83). The lengths of LWD from dry conifer forests ranges from 4.6-7.7m, from mesic conifer forests 4.8-12.3m, and from cold conifer forests 6-9m. It appears that drier forests produce slightly shorter debris than other forest types. This may result from lower precipitation limiting tree heights or from other influences such as successional stage, discharge, channel width and natural variation.

Interpretation of LWD lengths is easier when comparisons are made between dominant successional stage. Non-stocked forests (W.F. Thompson River) provide lengths of 6.0-7.8m, whereas immature/mature forests provide lengths of 7.5-8.2m lengths (Figure 20, pg. 83). If outlier streams are excluded (Crystal and Sunset) a pattern emerges relating longer lengths to more mature successional stages.

Comparisons of LWD lengths to gradient and to channel widths show that length increases with increasing gradient and decreasing channel width. As gradient increases from 0-15% wood length increases by 2m. Furthermore, as channel width increases from 1 to 4 meters, wood length decreases by 1 meter. Because high gradient channels are smaller and have low stream flows, the likelihood of a long pieces of LWD remaining in channel would increase. This may be the reason why I found slightly larger pieces of LWD.

<u>LWD Formation</u>

Table 13 (pg. 84) indicates that the type of wood formation is dependent on stream gradient. In extreme gradients (>18.5%) LWD occurs usually as a bridged or ramped piece because narrow channels can not accommodate the fallen material. High gradient channels (12.5-18.5%) are more variable; containing bridged or ramped pieces in areas outside of Thompson Falls and bridged and drift pieces in the Thompson Falls area. Channels are typically wider near Thompson Falls; resulting in more drift material. At gradients below 12.5% drift and bridged pieces predominate in most streams.

Table 5. SIGNIFICANCE LEVELS FOR LWD DENSITIES BETWEEN LOGGED AND UNLOGGED BASINS

PAIR	SIGNIFICANCE LEVEL	DIFFERENCE WITHIN PAIRS
CRYSTAL/ALLEN	P>.25	0.6/100M (U)
LUPINE/DEER	P=.025 *	20.0/100M (L)
FIRE/BIRD	P=.01 **	11.0/100M (L)
JORDAN/SUNSET	P=.10	6.4/100M (U)
HONEYMOON/W.F.THOMPSON	P=.10	5.3/100M (L)
SPRUCE/FOURLAKES	P=.05 *	4.8/100M (U)

*=SIGNIFIACNT, **=VERY SIGNIFICANT, ***=HIGHLY SIGNIFICANT
(U) OR (L) INDICATES STREAM WITH MORE WOODY DEBRIS PER 100 METERS

Table 6. MEANS AND STANDARD DEVIATIONS FOR THE NUMBER OF LARGE WOODY DEBRIS PER 100 METERS

STREAM	MEAN	STANDARD DEVIATION
CRYSTAL (U)	11.8	5.2
ALLEN (L)	11.1	6.4
LUPINE (U)	4.7	2.2
DEER (L)	24.3	27.5
JORDAN (U)	21.2	10.4
SUNSET (L)	14.8	6.5
FIRE (U)	21.3	12.6
BIRD (L)	32.1	10.9
SPRUCE (U)	17.2	5.2
FOURLAKES (L)	12.4	4.1
HONEYMOON (U)	23.7	6.7
W.F.THOMPSON (L)	29.1	11.6

Table 7. THE DENSITY OF LWD WITHIN PAIRED STREAMS

NUMBER PIECES PER 100 METERS

STREAM	0-10	11-20	21-30	31-40	41-50	51-60	61-70+
CRYSTAL (U)	56	33	11	-	-	-	-
ALLEN (L)	56	11	33	-	-	-	-
LUPINE (U)	100	-	-	-	-	-	-
DEER (L)	80	10	-	-	-	-	10
JORDAN (U)	17	16	50	16	-	-	-
SUNSET (L)	27	36	36	-	-	-	-
FIRE (U)	17	25	42	8	-	8	-
BIRD (L)	-	6	44	25	19	-	6
SPRUCE (U)	-	20	80	-	-	-	-
FOURLAKES (L)	38	50	12	-	-	-	-
HONEYMOON (U)	10	-	50	40	-	-	-
W.F.THOMPSON (L)	-	25	25	25	25	-	-
OVERALL AVG.							
LOGGED	34	23	25	8	7	0	3
UNLOGGED	33	16	39	11	0	1	0

Table 8. SIGNIFICANCE LEVELS FOR POTENTIAL LWD

BETWEEN LOGGED AND UNLOGGED BASINS

PAIR	SIGNIFICANCE LEVEL	DIFFERENCES WITHIN PAIRS
CRYSTAL/ALLEN	P=.025 *	18.7/100M (U)
LUPINE/DEER	P=.02 *	13.2/100M (U)
FIRE/BIRD	P=.20	9.2/100M (L)
JORDAN/SUNSET	P=.10	23.0/100M (L)
SPRUCE/FOURLAKES	P=.025 *	17.5/100M (U)
HONEYMOON/W.F.THOMPSON	P=.02 *	42.0/100M (U)

*=SIGNIFICANT **=VERY SIGNIFICANT ***=HIGHLY SIGNIFICANT
(U) OR (L) INDICATES STREAMS THAT HOLD MORE POTENTIAL DEBRIS

Table 9. PERCENT OF RIPARIAN ZONE HARVESTED WITHIN PAIRED STREAMS

STREAM	PERCENT HARVESTED
CRYSTAL (U)	0
ALLEN (L)	20.6
LUPINE (U)	0
DEER (L)	64.4
FIRE (U)	12
BIRD (L)	36.7
JORDAN (U)	0
SUNSET (L)	35.8
HONEYMOON (U)	0
W.F.THOMPSON (L)	68.2
SPRUCE (U)	0
FOURLAKES (L)	81.4

Table 10. SIGNIFICANCE LEVELS FOR LWD LENGTH

PAIR	SIGNIFICANCE LEVEL	DIFFERENCES WITHIN PAIRS
CRYSTAL/ALLEN	P=.02 *	2.23M (L)
LUPINE/DEER	P>.25	3.5M (U)
FIRE/BIRD	P>.25	0.7M (U)
JORDAN/SUNSET	P=.02 *	7.2M (L)
HONEYMOON/W.F.THOMPSON	P<.0005 ***	2.4M (U)
SPRUCE/FOURLAKES	P=.02 *	2.6M (U)

*=SIGNIFICANT, **=VERY SIGNIFICANT, ***=HIGHLY SIGNIFICANT
(U) OR (L) INDICATES STREAMS WITH LARGER DEBRIS LENGTHS

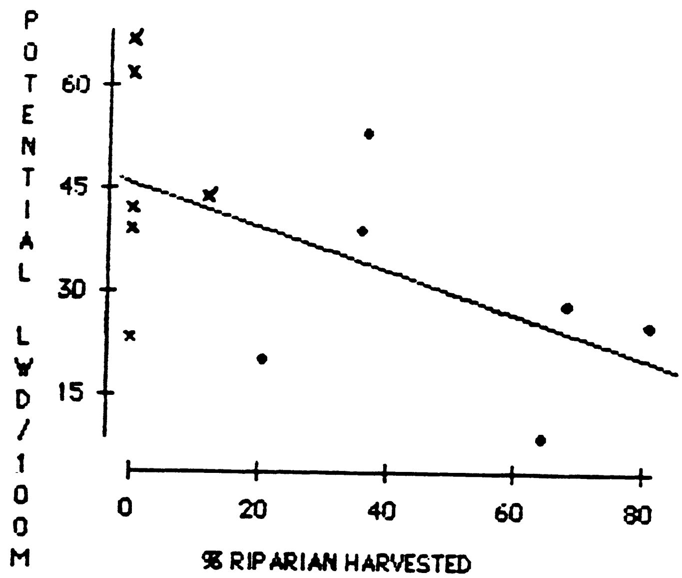

Figure 8. Relationship between potential LWD and percent of riparian zone harvested (r= -0.55; x's are unlogged and dots are logged).

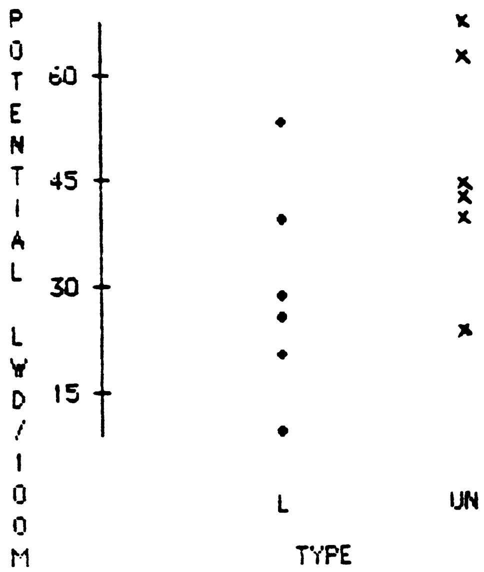

Figure 9. Potential LWD per 100 meters between logged and unlogged streams

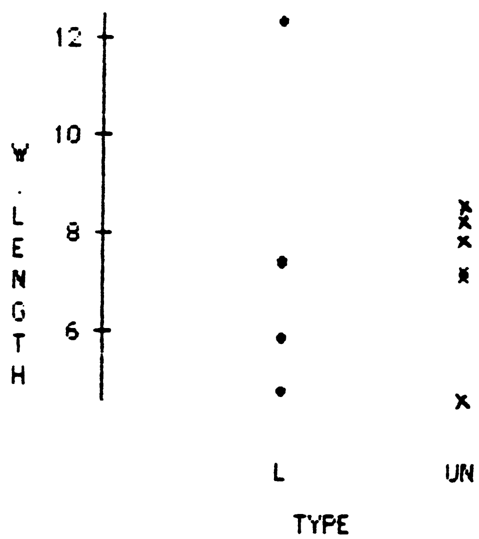

Figure 10. Avereage LWD length between logged and unlogged streams

Table 11. CHI-SQUARE SIGNIFICANCE LEVELS FOR LWD FORMATION

PAIR	SIGNIFICANCE LEVEL
CRYSTAL/ALLEN	$P>.25$
LUPINE/DEER	$P>.25$
FIRE/BIRD	$P=.05$ *
JORDAN/SUNSET	$P=.02$ *
HONEYMOON/W.F.THOMPSON	$P<.0005$ ***
SPRUCE/FOURLAKES	$P<.0005$ ***

*=SIGNIFICANT, **=VERY SIGNIFICANT, ***=HIGHLY SIGNIFICANT

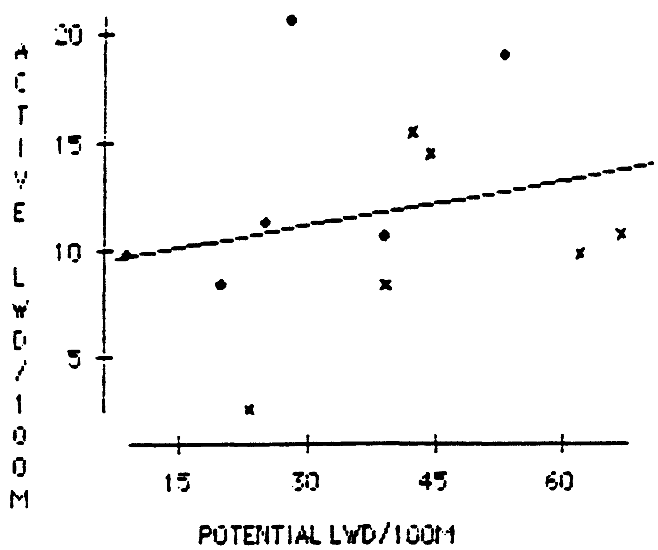

Figure 11. Regression of active LWD per 100 meters and potential LWD per 100 meters (r=.25) (x's are unlogged and dots are logged).

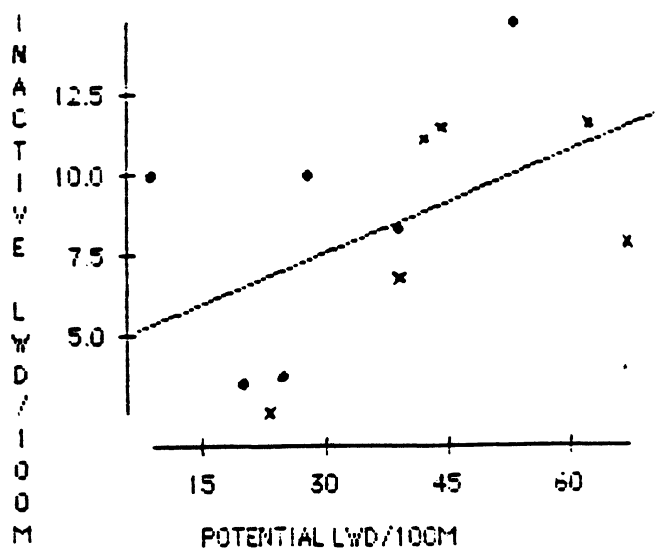

Figure 12. Regression of inactive LWD per 100 meters and potential LWD per 100 meters (r=.50) (x's are unlogged and dots are logged).

Table 12. MEANS AND STANDARD DEVIATIONS OF LWD PARAMETERS IN WET AND DRY STREAM TYPES

STREAM TYPE	ACTIVE LWD PER 100M	INACTIVE LWD PER 100M	LWD DIAMETER	LWD LENGTH
WET/LOGGED	16.5(9.8)[a]	10.2(7.8)	28(13.1)	7.4(6.2)
WET/UNLOGGED	13.3(7.4)	10.7(7.5)	31(13.9)	7.8(5.3)
DRY/LOGGED	5.3(5.7)	4.6(4.6)	23(12.6)	5.4(4.2)
DRY/UNLOGGED	5.8(7.6)	5.8(7.2)	27(12.5)	7.0(5.2)

MEAN(STD.DEV.)[a]

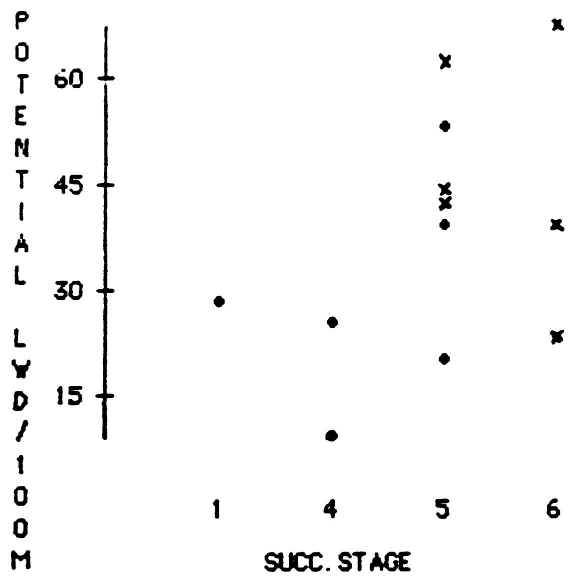

Figure 13. Dotplot of potential LWD and successional stage (1-non stocked; 4-pole; 5-immature; 6-mature). Dots are logged and x's are unlogged.

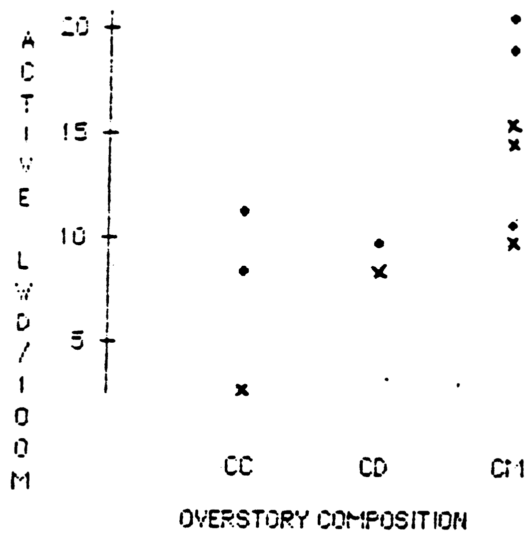

Figure 14. Relationship between active LWD and overstory riparian composition. (CC-spruce,subalpine fir;CD-ponderosa pine,western larch;CM-cedar,hemlock) x's are unlogged and dots are logged

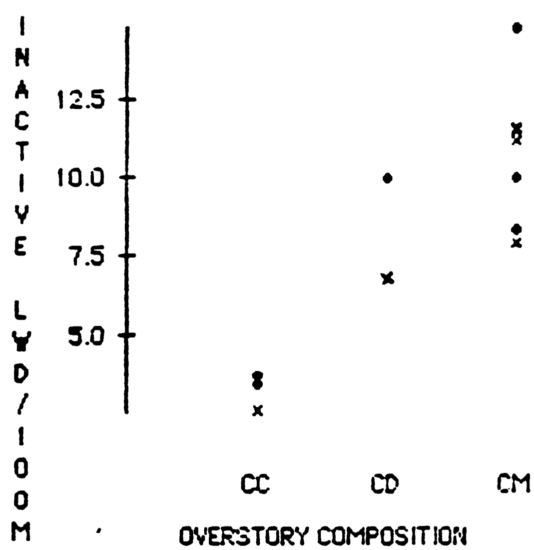

Figure 15. Relationship between inactive LWD and overstory riparian composition. (CC-spruce,subalpine fir; CD-ponderosa pine,western larch; CM-cedar,hemlock) x's are unlogged and dots are logged

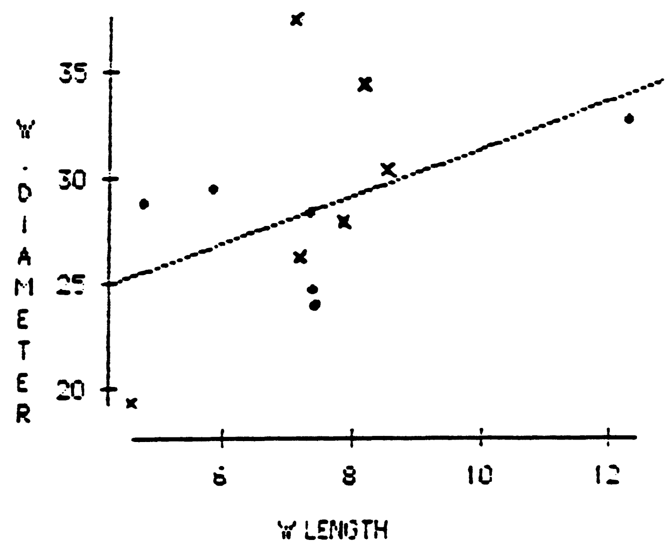

Figure 16. Comparison of LWD diameter and LWD length in logged (dots) and unlogged (x's) streams. Note that most logged streams have smaller diameters and lengths (R=0.45)

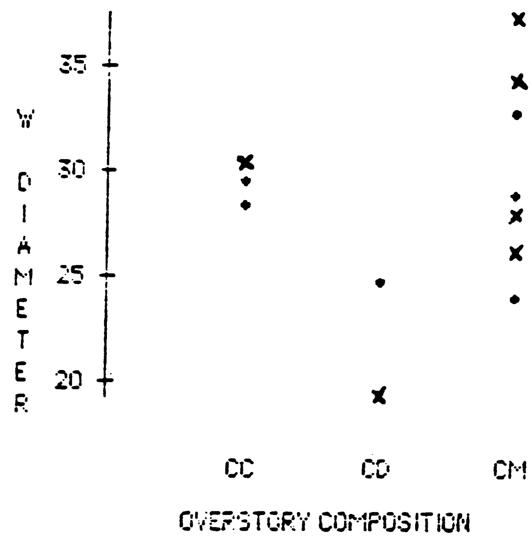

Figure 17. LWD diameter by overstory riparian composition (CC-spruce,subalpine fir;CD-ponderosa pine,western larch;CM-cedar, hemlock) x's are unlogged and dots are logged

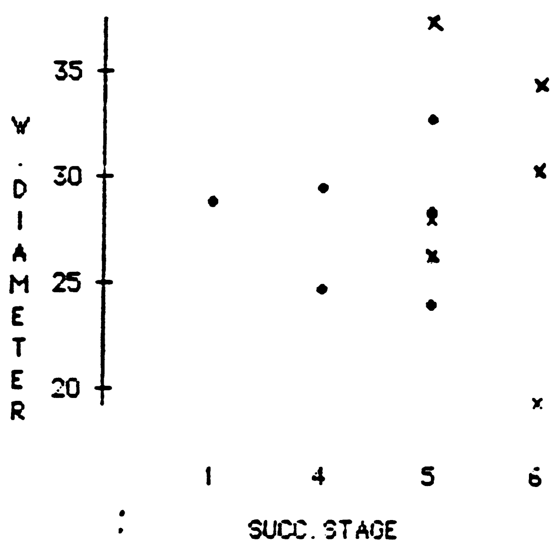

Figure 18. LWD diameter by successional stage (1-nonstocked; 4-pole; 5-immature; 6-mature) x's are unlogged and dots are logged

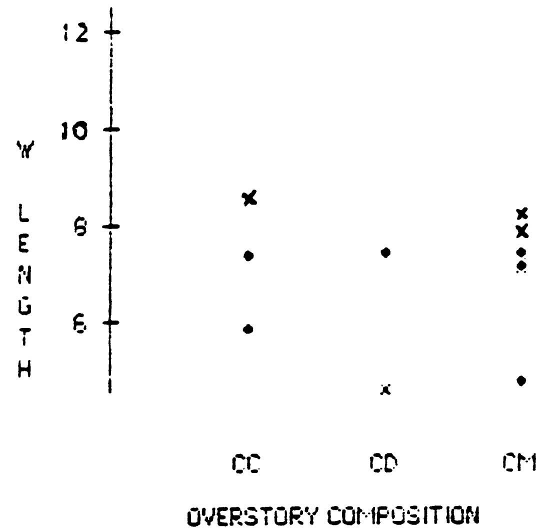

Figure 19. LWD length by overstory composition (CC-spruce, subalpine fir; CD-ponderosa pine, western larch; CM-cedar, hemlock) x's are unlogged and dots are logged

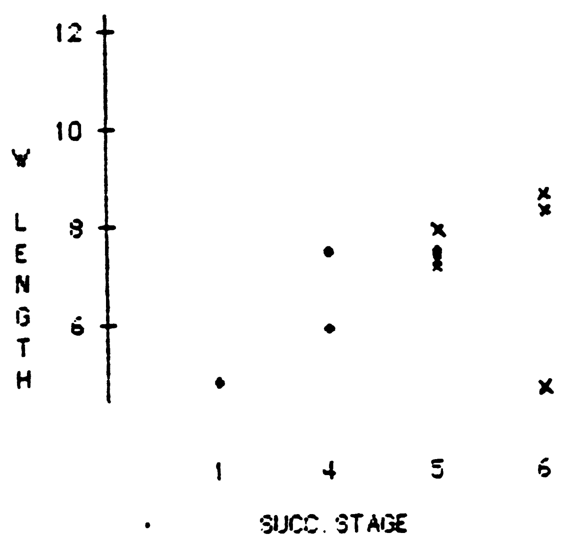

Figure 20. LWD length by successional stage (1-non stocked; 4-pole size; 5-immature; 6-mature) x's are unlogged and dots are logged

Table 13. THE TWO DOMINANT LWD FORMATION TYPES BY STREAM GRADIENT

STREAM	LOW GRADIENT (0-5%)	MODERATE GRADIENT (5-12.5%)	HIGH GRADIENT (12.5-18.5%)	EXTREME GRADIENT (>18.5%)
CRYSTAL (U)	B/D	B/CB	B/CB	-
ALLEN (L)	B/D	B/D	-	-
LUPINE (U)	B/D	-	-	-
DEER (L)	B/D	B/R	B/R	-
JORDAN (U)	D/B	B/D	B/R	B/R
SUNSET (L)	B/R	D/R	CB/R	B/R
FIRE (U)	B/D	D/R	B/D	B/R
BIRD (L)	B/D	B/D	B/R	B/R
SPRUCE (U)	-	D/B	B/D	-
FOURLAKES (L)	-	D/R	D/R	-
HONEYMOON (U)	-	B/R	B/R	B/R
W.F.THOMPSON (L)	D/R	B/D	B/D	-

BRIDGE(B), DRIFT(D), COLLAPSED BRIDGE(CB), RAMP(R)

Section 3

Substrate Composition

Substrate composition was sampled to determine if particle size distribution had been altered. Fines (<0.6 cm) provide the most direct indication of management impacts; however, other particle sizes could be indicators. For example, fewer 0.6-15.2 cm particles would indicate a reduction in spawning gravels used by resident and adfluvial trout (U.S.F.S., 1991b). Larger particles can also indicate stability of streambed armoring or the effects of increased discharge brought about by harvest activity.

Originally I had hoped the Wolman Pebble Count would measure accumulated fines, but I soon realized that the pebble count favored larger particle sizes. MacDonald et al. (1991) also notes this techniques to be biased against selecting very small particles. Substrate smaller than 0.6 cm were probably collected at a lower frequency than were actually present. Therefore, I feel that statistical tests do not reflect the true abundance of fines.

Chi-square analysis indicated that three logged basins (W.F. Thompson River, Deer, Sunset) differ significantly from their controls in pool substrate composition and one logged basin (W. F. Thompson River) differ significantly from its control in riffle substrate composition. Many logged basins have road densities above (> 4.5 mi/mi^2) (Table 15, pg. 88). Chi-square residuals reveal that most harvested basins consistently contain more fines and small gravels than their control streams. Four harvested basins (W.F. Thompson River, Fourlakes, Deer, and Allen) hold more fine material in riffles (Table 17, pg. 90). Three harvested basins (W.F. Thompson River, Fourlakes and Deer) hold more fines in pools; two (Bird and Sunset) contain fewer fines than their control and one (Allen) is not different from its control (Table 16, pg. 89).

Correlations of fines with road density, road mileage, percent of riparian zone harvested, WATSED output, percent of watershed impacted and eroding banks were attempted. Unfortunately, none provided information to indicate what factors are linked to accumulation of fines.

Particle-size distribution is shown in Tables 16 (pg. 89) and 17 (pg. 90) for surveyed pool and riffle habitats. In most streams, pools and riffles are dominated by rubble (7.6-30.5 cm) and gravel (0.6-7.6 cm). Rubble and gravel proportions are roughly equal (± 10%) in most pairs; however, in four streams [Lupine (U), Deer (L), Sunset (L) and Allen (L)] riffles are dominated by gravels (>52%). Of these four, Deer Creek has 62% more gravel than rubble. Overall, pool substrates in harvested streams consist of 20.2% fines compared to 11.7% in control streams. Also, riffles in harvested streams contain slightly more fines, having 8.2% compared to 5.0% in unharvested streams. Therefore, it appears that harvesting affects substrate composition.

Table 14. CHI-SQUARE SIGNIFICANCE LEVELS FOR POOL AND RIFFLE SUBSTRATE COMPOSITION

PAIR	POOL SUBSTRATE	RIFFLE SUBSTRATE
CRYSTAL/ALLEN	P>.25	P>.25
LUPINE/DEER	P<.0005 ***	P>.25
FIRE/BIRD	P=.15	P>.25
JORDAN/SUNSET	P=.001 ***	P=.10
HONEYMOON/W.F.THOMPSON	P=.05 *	P=.05 *
SPRUCE/FOURLAKES	P=.15	P=.15

*=SIGNIFICANT, **=VERY SIGNIFICANT, *** HIGHLY SIGNIFICANT

Table 15. COMPARISON OF "WATSED" PREDICTED FINES AND AVERAGE PEBBLE COUNT FINES WITHIN PAIRED STREAMS

STREAM	POOL FINES	RIFFLE FINES	[a]MAX.%	[b]LEVEL %	[c]AVG.%	ROAD DENSITY (MI/MI^2)
CRYSTAL (U)	4	2	-	-	-	0.2
ALLEN (L)	3	5	304	109	156	2.5
LUPINE (U)	27	8	-	-	-	-
DEER (L)	73	13	1177	372	545	6.6
JORDAN (U)	10	7	-	-	-	-
SUNSET (L)	6	6	363	254	294	5
FIRE (U)	18	13	193	107	150	1
BIRD (L)	19	12	244	131	159	3.5
SPRUCE (U)	5	0	-	-	-	-
FOURLAKES (L)	11	6	464	250	334	3.6
HONEYMOON (U)	6	0	37	18	-	1.2
W.F.THOMPSON (L)	19	7	418	228	299	4.5

[a]MAX%-MAXIMUM SEDIMENT INCREASE OVER NATURAL
[b]LEVEL%-BASELINE SEDIMENT INCREASE OVER NATURAL AFTER HARVEST
[c]AVG.%-AVERAGE SEDIMENT INCREASE OVER NATURAL (1975-1992)

Table 16. POOL SUBSTRATE COMPOSITION DETERMINED BY WOLMAN PEBBLE COUNT

STREAM	BEDROCK	BOULDER	LARGE RUBBLE	SMALL RUBBLE	COARSE GRAVEL	SMALL GRAVEL	SAND AND SILT
CRYSTAL (U)	2	7	12	19	26	34	4
ALLEN (L)	0	10	16	16	23	33	3
LUPINE (U)	0	0	8	11	19	32	27
DEER (L)	0	0	1	0	0	26	73
JORDAN (U)	8	4	13	23	27	35	10
SUNSET (L)	0	2	7	14	26	52	6
FIRE (U)	3	6	10	40	23	14	18
BIRD (L)	0	7	14	33	29	22	9
SPRUCE (U)	12	6	9	43	27	13	5
FOURLAKES (L)	9	8	13	25	24	19	11
HONEYMOON (U)	14	11	9	38	21	16	6
W.F.THOMPSON (L)	14	5	12	28	20	20	19
OVERALL AVG.							
LOGGED	3.8	5.3	10.5	19.3	20.3	28.7	20.2
UNLOGGED	6.5	5.6	10.2	29	23.8	24	11.7

ALL VALUES IN PERCENT

Table 17. RIFFLE SUBSTRATE COMPOSITION DETERMINED BY WOLMAN PEBBLE COUNT

STREAM	BEDROCK	BOULDER	LARGE RUBBLE	SMALL RUBBLE	COARSE GRAVEL	SMALL GRAVEL	SAND AND SILT
CRYSTAL (U)	2	16	22	21	23	21	2
ALLEN (L)	7	12	17	14	25	27	5
LUPINE (U)	0	0	8	16	23	38	8
DEER (L)	0	0	6	10	24	55	13
JORDAN (U)	3	8	17	30	21	23	7
SUNSET (L)	4	10	9	19	23	36	6
FIRE (U)	4	9	13	34	23	19	13
BIRD (L)	3	11	16	29	25	19	12
SPRUCE (U)	6	16	19	24	18	21	0
FOURLAKES (L)	5	10	18	21	27	21	6
HONEYMOON (U)	11	10	17	25	24	20	0
W.F THOMPSON (L)	4	6	16	23	25	24	7
OVERALL AVG.							
LOGGED	3.8	8.2	13.7	19.3	24.8	30.3	8.2
UNLOGGED	4.3	9.8	16	25	22	23.7	5

ALL VALUES IN PERCENT

Section 4

Channel Condition

Changes in channel dimensions were determined from the analysis of seven variables: pool and riffle length, width, depth and maximum depth, eroding banks, overhead cover and habitat area. Paired t-tests indicated that channel widths were significantly and consistently wider in harvested basins than unharvested. Harvested basins have wider pool and riffle habitat in Allen, Deer, Sunset, Fourlakes and Bird Creeks. Riffles average 0.3 to 0.6 m wider ($p<0.01$) and pools 0.2 to 0.8m wider ($p=0.007$) than control streams. Only the W.F. Thompson River (L) does not have significantly wider habitat.

Paired t-tests for water depth showed that riffles are significantly deeper ($p=0.05$) in harvested basins than in unharvested. Pools however, were not significantly deeper ($p=0.30$). Two sample t-tests indicated that three harvested basins (Allen, Deer and Sunset) contain significantly deeper (5.2-9.3 cm) pool habitat. Fire Creek is the only unharvested stream to have deeper pools, averaging 5.2 cm deeper. Three harvested basins (Allen, Deer and Sunset) also have significantly deeper riffle habitat. Overall, five logged streams hold deeper riffles, averaging 0.4 cm - 4.0 cm deeper. Again, only Fire Creek (U) has deeper riffles, averaging 21.7 cm deeper.

Riffle and pool lengths were not significantly different between harvested and unharvested basins (paired t-test, $p>0.05$). Examination by two sample t-tests of individual pairs show that riffle lengths are significantly longer in two streams [Allen (L) and Honeymoon (U)] and pool lengths significantly longer in five streams [Crystal (U), Deer (L), Sunset (L), W.F. Thompson River (L) and Fire (U)] (Table 18, pg. 96). Riffles in significant streams average 17.2 m to 33.0 m longer, while pools in significant streams average 0.3 m to 1.4 m longer than their controls. However, results are not conclusive because both logged and unlogged streams hold longer habitat units.

Eroding Banks and Overhead Cover

Harvested basins generally contain more eroding banks (4.5m/100m) than their controls (2.6m/100m), however differences were not statistically significant (paired t-test $p>0.25$). In fact, two sample t-tests shows only Fourlakes Creek having significantly more eroding banks (2.0m/100m) than its control. Bank material consists of larger particles that are very resistant to channel erosion in monitored streams. In addition, no skid trail crossings were found to decrease bank stability.

Paired t-tests showed that in overhead bank cover was not significantly different between logged and unlogged basins ($p>0.32$). Two sample t-tests reveal that only two streams [Honeymoon (U) and Bird (L)] have significantly more overhead cover. Bird Creek averages 20.0m/100m more overhead cover than its control, while Honeymoon Creek averages 7.4m/100m more. In both instances extensive mature riparian stands are present in select reaches, increasing rootwad material that forms overhead bank cover.

Habitat Area

Paired t-tests revealed no statistical difference in average riffle area between harvested and unharvested basins. Analysis of individual pairs indicate that three harvested basins (Allen, Deer and Fourlakes) and two unharvested basins (Honeymoon and Fire) hold more riffle area than their comparison stream. Hence, riffle area may be more reflective of cascade dominated streams than changes caused by logging.

Pool area was significantly larger ($3.12m^2$) in harvested basins than unharvested ($p=0.04$, paired t-test). Two sample t-tests revealed that several harvested basins (Deer, Bird, Fourlakes and W.F. Thompson River) have significantly larger pools (1.7-$8.0m^2$) than their controls. Logging may have enlarged pools due to higher induced water yields (Table 19, pg. 97).

Scatterplot Analysis

Gradient influences pool frequency. Pools were significantly correlated with gradient in Crystal, Deer, Lupine, Sunset, Jordan and Spruce Creeks (Table 20, pg. 98). Pools in Fourlakes and Fire Creeks, though not significantly correlated with gradient, followed a similar pattern. Three streams illustrate gradient's influence upon pools: (1) Crystal Creek (U), averages 3 pools per 100m at 2.5% gradient, 2/100m at 7.5%, and 1.0/100m at 10%; (2) Jordan Creek (U), averages 3 pools per 100m at 6%, 2/100m at 13% and 0/100m at 21%; and (3) Spruce Creek (U), averages 3.5 pools per 100m at 12%, 2.0/100m at 16% and 0/100m at 19%. While pool frequency varies with gradient and pool formative features, pool frequency consistently declines toward headwater areas.

In only one instance did pools increase as gradient increased. Allen Creek has 0.6 pools per 100m at 4.0%, 1.0/100m at 6.0% and 1.5/100m at 8%. I suspect natural variation as well as logging created more pools because cut logs were found in higher gradient reaches. The logs may have been incorporated into the streambed causing more pools to form.

Pool frequency was also significantly correlated with active LWD within the stream channel (Figure 21, pg. 100). Streams with less than 5 active pieces of LWD per 100m have .77 pools per 100m, streams with 10 active pieces of LWD/100m have 1.0 to 2.0 pools per 100m and streams with 15-20 active pieces of LWD/100m have 1.5 to 2.5 pools per 100m. Thus, the more LWD streams hold, the more pools are likely to form. However, this pattern is not consistent in every streams. Sunset and Deer Creeks each average 10 active/100m, but have only 0.7 and 0.2 pools per 100m respectively. This is due primarily to an overabundance of shallow cascade habitat that contains few pools, but holds LWD. In this case, LWD is too large to be incorporated into the channels resulting in many bridged pieces but no pools.

Pools are of particular importance in high gradient streams because most habitat is dominated by cascades. In fact pool area rarely exceeded 10% of stream area and often decreases as gradient increases. Rearing habitat is limited to low (0-5%) and moderate (5.1-12.5%) gradients. Table 21 (pg. 99) shows that in only one stream (Spruce Creek) does pool area become abundant above 12.5%. This then emphasizes the importance of protecting headwater areas because increases in sediment or water will most certainly have a profound affect upon downstream channels and pool habitat.

Table 18. SIGNIFICANCE LEVELS FOR RIFFLE AND POOL LENGTHS

PAIR	RIFFLE	POOL
CRYSTAL/ALLEN	P<.005 ***	P<.0005 ***
LUPINE/DEER	P=.20	P=.005 **
JORDAN/SUNSET	P>.25	P=.05 *
FIRE/BIRD	P=.20	P=.025 **
HONEYMOON/W.F.THOMPSON	P=.005 **	P<.005 **
SPRUCE/FOURLAKES	P>.25	P>.25

*=SIGNIFICANT, **=VERY SIGNIFICANT, ***=HIGHLY SIGNIFICANT

Table 19. PREDICTED "WATSED" WATER YIELDS

STREAM	AVERAGE WATER YIELD IN ACRE FEET	[a] PEAK %	[b] AVGERAGE PEAK %
CRYSTAL (U)	1082	1	-
ALLEN (L)	1159	8	7
LUPINE (U)	4975	-	-
DEER (L)	7252	15	12
JORDAN (U)	3360	1	1
SUNSET (L)	3277	5	5
FIRE (U)	5359	2	2
BIRD (L)	5938	8	6
SPRUCE (U)	6750	-	-
FOURLAKES (L)	12046	7	6
HONEYMOON (U)	9750	4	4
W.F.THOMPSON (L)	9071	11	10

[a] PEAK %-PERCENT INCREASE IN YEARLY MEAN WATER YIELD OVER NATURAL
[b] AVG. PEAK-PERCENT AVERAGE INCREASE IN WATER YIELD OVER NATURAL

Table 20. CORRELATIONS OF STREAM GRADIENT AND NUMBERS OF POOLS PER 100 METERS

STREAM	CORRELATION VALUE	R^2	SIGNIFICANCE AT .05 ALPHA
CRYSTAL	-0.762	58.1	*
ALLEN	0.538	29	*
LUPINE	-0.88	77.4	*
DEER	-0.573	32.8	*
JORDAN	-0.566	32	*
SUNSET	-0.98	96.1	*
FIRE	-0.38	14.4	-
BIRD	-0.1	-	-
SPRUCE	-0.745	55.4	*
FOURLAKES	-0.289	8.3	-
HONEYMOON	-0.06	-	-
W.F.THOMPSON	-0.11	-	-

Table 21. PERCENTAGE OF POOL AREA BY STREAM GRADIENT

STREAM	LOW GRADIENT 0-5%	MODERATE GRADIENT 5-12.5%	HIGH GRADIENT 12.5-18.5%	EXTREME GRADIENT >18.5%
CRYSTAL	70	29	5	-
ALLEN	38	48	14	-
LUPINE	100	-	-	-
DEER	95	5	-	-
JORDAN	38	17	20	21
SUNSET	-	88	12	-
FIRE	26	52	19	3
BIRD	6	74	17	3
SPRUCE	-	34	66	-
FOURLAKES	-	95	5	-
HONEYMOON	-	63	18	19
W.F.THOMPSON	10	72	18	-

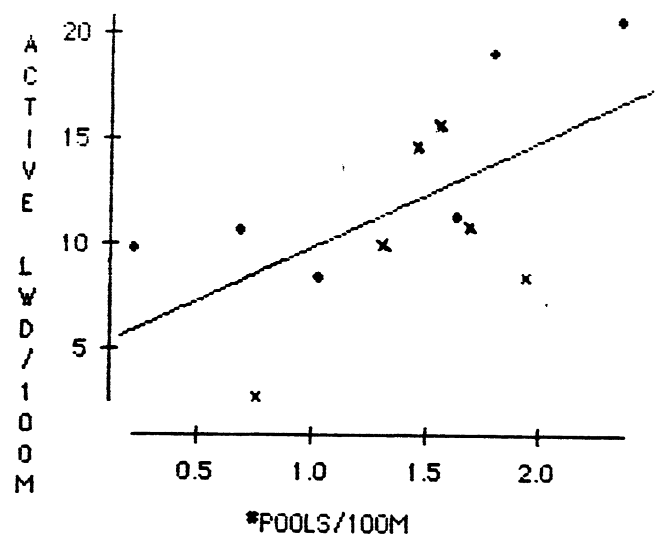

Figure 21. Correlation of active LWD per 100 meters and the number of pools per 100 meters (r=0.62) x's are unlogged dots are logged

Section 5

Riparian Impacts

Canopy Closure

Spherical canopy closure, a measure of shading by overstory vegetation, was significantly different between logged and unlogged riparian stands (paired t-test, $p<0.05$). Most harvested stands average 38.0-55.3 percent canopy closures with a few (Allen and Bird) near 70%. In contrast, unharvested stands average 69-92.4 percent canopy closures.

Canopy closure was significantly correlated with the degree of riparian disturbance (Figure 22, pg. 105). As riparian logging increased canopy closure decreased. Streams with 10-20% riparian harvest average 79-86% closures, with 38% harvest average 55.0-72.0% closures, and with over 60% harvest average 38-47.0 percent closures.

Logged riparian stands naturally held less mature successional stages and less dense canopy closures (Figure 23, pg. 106). Non-stocked forest (1) average 45.0% closures, pole sized forest (4) average 38-47.3% closures, immature forests (5) average 71.7-92.4% closures and mature forests (6) average 69-87.3% closures. It appears that once trees approach a DBH of 22.9 cm or larger (immature to mature trees), sufficient cover is available to shade most streams.

Successional Stage

Four logged riparian stands (Deer, Fourlakes, Bird and W.F. Thompson River) have significantly different riparian successional stages (Table 22, pg. 106). Residual analysis of significant stands reveals that the W.F. Thompson River and Bird Creek contain more non-stocked (<300 trees/acre) riparian forest than their controls, while Deer and Fourlakes Creeks contain more seedling (<1.4m tall) and sapling (>1.4m tall and DBH<12.7cm) riparian forest. Clearcuts on first and second order channels were directly responsible for the successional changes.

Table 23 (pg. 107) shows that overall, unharvested riparian zones are composed of 52.8% mature, 31.0% immature and 13.8% pole size forests. In contrast harvested riparian zones have 36.3% mature, 25.2% immature and 7.7% pole size forests. Furthermore, 31.7% of harvested riparian stands are below a 12.7cm DBH, while unharvested stands have but 1.0% below this diameter size.

Figure 24 (pg. 108) further emphasizes those streams with over 60% riparian harvests have earlier successional stages. Stands with limited riparian logging (Allen) or sparce disturbance (Sunset and Bird) have successional stages comparable to other unharvested stands.

Overhanging Vegetation

Overhanding vegetation is similar within most pairs (p=0.38). Two sample t-test indicated that Allen Creek (L) is the only stream to have more overhanging vegetation (36.8m/100m) than its control Crystal Creek (Table 22, pg. 106). Lupine (U) (13.8m/100m) and Bird (L) (16.5m/100m) Creeks also hold more overhanging vegetation, however neither stream was significant due to their small sample size.

Basins in drier climates (<40" precipitation annually) hold more overhanging vegetation than basins in wetter, more shaded sites. For example, in Deer, Lupine and Allen Creeks 50% of all banks have overhanging vegetation. Conversely, basins in wetter climates, (>40" precipitation annually) have banks with only 0.2 to 15.6 percent overhanging vegetation.

Overstory Riparian Vegetation

Chi-square analysis indicated that five streams (Bird, Deer, Fourlakes, Allen and W.F. Thompson River) have significantly different overstories from their control streams (Table 22, pg. 106). Riparian stand density and species composition often varied widely between streams. Variations in soil rockiness, slope steepness, terrace width, and mortality from disease contributed to a patchy distribution of trees. For example, Allen Creek has very little riparian logging and 82% of its overstory is composed of spruce (CC). In contrast, its control Crystal

Creek's overstory has 27% spruce and 42% ponderosa pine, douglas-fir, and western larch (Table 24, pg. 109).

In only three streams (Bird, Fourlakes and W.F. Thompson River) is it obvious that riparian harvests changed overstory composition. Each logged riparian stand holds more alder and willow (SR) than its control. In fact harvested stands contain 15-37 percent in the (SR) category, compared to 6-10 percent for unharvested streams (Figures 25, pg 111).

Understory Riparian Vegetation

Understory canopy is composed primarily of alder, willow, thimbleberry and dogwood (SR) regardless of harvest activity (Table 25, pg. 110). Other dominant understories are fern (FE), seedling trees (TS), dwarf shrubs (SW) and grasses (GD).

Chi-square analysis revealed that four harvested riparian stands (Deer, Fourlakes, Sunset and Bird) have significantly different understory compositions than their control (Table 25, pg. 110). In harvested areas alder and willow becomes both the dominant understory and overstory and overstory. However, other changes are more difficult to conclude because understories are quite variable and riparian disturbances limited in some streams.

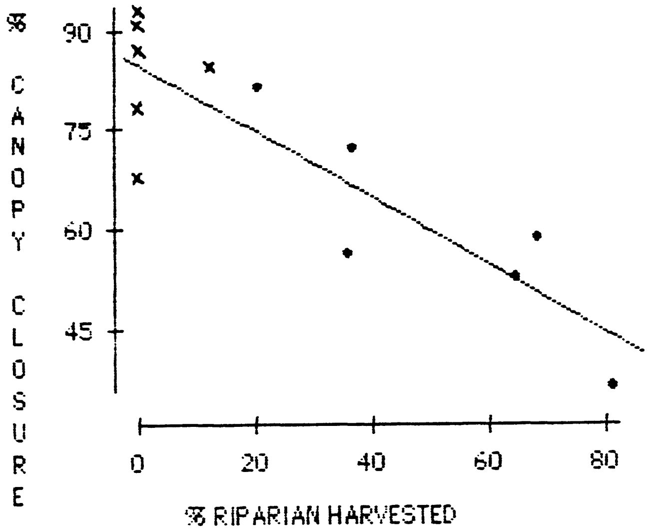

Figure 22. Correlation of canopy closure and percent of riparian zone harvested (r= -0.88) x's are unlogged and dots are logged

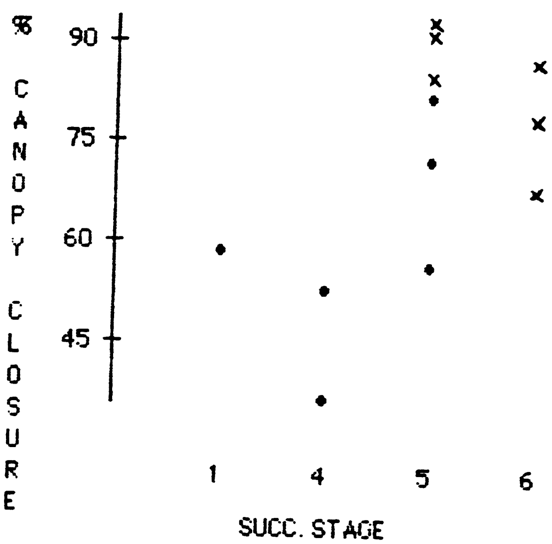

Figure 23: Canopy closure by successional stage (1-non stocked; 4-pole; 5-immature; 6-mature) x's are unlogged and dots are logged

Table 22. SIGIFICANCE LEVELS FOR RIPARIAN PARAMETERS BETWEEN LOGGED AND UNLOGGED BASINS

PAIR	CANOPY CLOSURE	OVERHANGING VEGETATION	SUCCESSIONAL STAGE	OVERSTORY COMPOSITION	UNDERSTORY COMPOSITION
CRYSTAL/ALLEN	-	*	-	**	-
LUPINE/DEER	**	-	***	***	*
JORDAN/SUNSET	***	-	-	-	***
FIRE/BIRD	**	-	**	*	**
HONEYMOON/W.F.THOMPSON	***	-	**	*	-
SPRUCE/FOURLAKES	***	-	**	***	***

*=SIGNIFICANT(P=0.05) **=VERY SIGNIFICANT(P=0.01) ***=HIGHLY SIGNIFICANT (P=0.001)

Table 23. RELATIVE FREQUENCY OF RIPARIAN SUCCESSIONAL STAGES BETWEEN LOGGED AND UNLOGGED BASINS

STREAM	NON-STOCKED	SEEDLING 3-10 YEARS OLD	SAPLING 10-40 YEARS OLD	POLE 40-70 YEARS OLD	IMMATURE 70-120 YEARS OLD	MATURE 120-160 YEARS OLD
CRYSTAL (U)	-	-	-	-	25	65
ALLEN (L)	-	-	-	-	60	40
LUPINE (U)	-	-	-			100
DEER (L)	12	-	13	12	38	25
JORDAN (U)	-	-	-	29	29	43
SUNSET (L)	-	-	-	-	43	27
FIRE (U)	6	-	-	24	53	18
BIRD (L)	17	4	-	-	39	39
SPRUCE (U)	-	-	-		9	91
FOURLAKES (L)	8	-	23	23	15	31
HONEYMOON (U)	-	-	-	30	70	-
W.F.THOMPSON (L)	47	-	-	11	16	26
OVERALL AVG.						
LOGGED	14	0.7	16.1	7.7	25.2	36.3
UNLOGGED	0.7	-	-	13.8	31	54.5

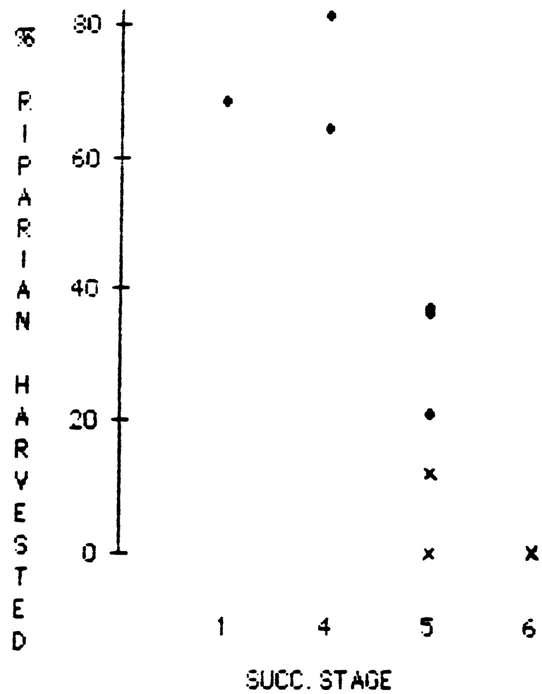

Figure 24. Changes in successional stage caused by riparian harvesting. x's are unlogged and dots are logged

Table 24. FREQUENCY OF RIPARIAN OVERSTORY TYPES

STREAM	CD[a]	CC[b]	CM[c]	SR[d]	SD[e]
CRYSTAL (U)	42	27	13	18	-
ALLEN (L)	18	82	-	-	-
LUPINE (U)	20	60	-	20	-
DEER (L)	40	40	-	20	-
JORDAN (U)	-	-	100	-	-
SUNSET (L)	-	-	100	-	-
FIRE (U)	6	-	88	6	-
BIRD (L)	-	22	52	22	4
SPRUCE (U)	-	18	82	-	-
FOURLAKES (L)	-	-	85	15	-
HONEYMOON (U)	-	-	90	10	-
W.F.THOMPSON (L)	-	16	47	37	-

[a](CD)-PONDEROSA,DOUGLAS-FIR,WESTERN LARCH; [b](CC)-LODGEPOLE,SUBALPINE FIR, WHITEBARK PINE
[c](CM)-CEDAR,GRAND FIR,SPRUCE; [d](SR)-ALDER,WILLOW
[e](SD)-MAPLE,HAWTHORN,NINEBARK

Table 25. FREQUENCY OF RIPARIAN UNDERSTORY TYPES

STREAM	SR[a]	SD[b]	SW[c]	FE[d]	TS[e]	XX[f]
CRYSTAL (U)	60	18	13	9	-	-
ALLEN (L)	95	-	-	-	5	-
LUPINE (U)	70	-	10	-	-	20
DEER (L)	80	-	20	-	-	-
JORDAN (U)	10	-	-	-	90	-
SUNSET (L)	100	-	-	-	-	-
FIRE (U)	70	-	12	-	-	18
BIRD (L)	57	4	-	39	-	-
SPRUCE (U)	46	-	-	-	46	8
FOURLAKES (L)	92	8	-	-	-	-
HONEYMOON (U)	63	4	-	-	-	37
W.F.THOMPSON (L)	64	-	-	-	-	32

[a](SR)-ALDER,WILLOW; [b](SD)-MAPLE,HAWTHORN,NINEBARK
[c](SW)-<2.5FT TALL WILLOW AND OCEANSPRAY; [d](FE)-FERN
[e](TS)-TREE SEEDLING OR SAPLING; [f](XX)-NON VEGETATED

Figure 25. Alders that became the dominant overstory after riparian harvesting.

Section 6

Stream Temperature

Paired t-test indicated that maximum (P = 0.83) and minimum (P = 0.83) temperatures were not significantly different between logged and unlogged basins. Harvested basins followed no general pattern, with three having higher maximum temperatures (1.7 to 2.8°F higher) and three having lower maximum temperatures (0.2 to 2.4°F lower) than their controls. In contrast, most harvested basins have higher average minimum temperatures (0.7 to 4.3°F) than control streams.

Although average temperatures were similar, harvested basins' temperatures fluctuate more than unharvested basins (Table 26, pg. 114). For example, Deer, Sunset, Bird and W. F. Thompson River have all maximum temperatures that fluctuate 2 to 3°F higher than their unlogged counterpart. Minimum temperatures did not follow this pattern, with streams varying by no more than 1 to 1.5°F.

Overall, temperatures ranged from a high of 65°F (18.5°C) in Deer Creek to a low of 33°F (0.6°C) in the W. F. Thompson River. Most streams averaged maxima of 40 to 57°F (4.5 to 14°C) and minima of 38 to 48°F (3.4 to 9.0°C).

Lower elevational streams generally have warmer temperatures than streams with prolonged snowpack and cooler air temperatures. Higher elevational streams near Thompson Falls averaged maximums of 45.5°F (7.5°C) and minimums of

40.7°F (4.9°C). In contrast, other lower elevational streams averaged maximums of 54.6°F (12.7°C) and minimums of 44.7°F (7.1°C).

Table 26. MAXIMUM AND MINIMUM BIWEEKLY TEMPERATURES WITHIN PAIRED STREAMS

STREAM	AVERAGE MAXIMUM	STANDARD DEVIATION	AVERAGE MINIMUM	STANDARD DEVIATION
CRYSTAL (U)	57.0	3.0	48.3	3.2
ALLEN (L)	55.5	2.1	47.0	3.5
LUPINE (U)	55.1	2.5	41.6	3.3
DEER (L)	54.9	5.6	42.3	2.6
JORDAN (U)	50.0	1.7	43.9	1.5
SUNSET (L)	51.8	3.0	45.4	2.3
FIRE (U)	55.4	1.7	44.0	2.6
BIRD (L)	57.1	3.0	45.3	3.7
SPRUCE (U)	51.0	2.4	46.1	2.3
FOURLAKES (L)	47.6	2.6	41.8	1.7
HONEYMOON (U)	40.1	1.7	37.1	1.1
W.F.THOMPSON (U)	43.0	4.1	37.9	2.2

ALL VALUES IN °F

DISCUSSION

The following sections will interpret the results on an individual parameter basis to help clarify the discussion.

Fish Habitat

Structural Association

Pool structural associations are similar within pairs suggesting that timber harvest impacts were limited. To alter a pool's structure increases in discharge, sediment or the amount and composition of LWD must occur. Although riparian harvesting took place, no inchannel LWD was cleared (Dick Kramer, Lolo National Forest, Personal Communication). Furthermore, WATSED analysis identified only three streams (W.F. Thompson River, Deer, and Allen) to have predicted discharge increases above the 10% threshold thought to disturb channel equilibrium. Hence, LWD and its role as a pool creator should have been unaffected by high flows.

The frequency of LWD formed pools were not significantly different within pairs. Overall, LWD forms 48% of pools in logged basin compared to 41% in unlogged basins. However, instances of higher debris loading occurs in several logged basins. Bird Creek (L) and the W.F. Thompson River (L) have an abundance of LWD when comparisons are restricted to reaches with similar gradients. In each reach, the number of LWD pieces per 100 meters is higher for the logged basin than the unlogged. Yet only one harvested basin (W.F. Thompson River) contains more LWD formed pools. A possible explanation for the disparity is that reaches within W.F. Thompson River have at least 50% of all LWD completely within the low flow channel. In contrast, Bird Creek has only 11% to 20% of its LWD in the low flow channel. It appears with more debris completely within the channel, the greater chance streambed scour will initiate pool formation. Figure 26 (pg. 147) reveals that a high percentage of LWD lengths in the W.F. Thompson River are shorter than 5 meters. In contrast, Bird Creek has a high proportion of lengths longer than 5 meters, hence LWD is too long in relation to the channel and fewer pools were formed (Figure 27, pg. 148).

Other structural features, such as boulders and falls, would not be expected to change from timber harvests unless substantial channel alterations were made. As Chamberlin, et. al. (1991) notes channel environments of higher gradient streams are often controlled by bedrock, woody debris or armoring layers (boulder and cobbles). Because of their stability they are difficult to modify.

<u>Habitat Type</u>

Several logged basins contain greater numbers of riffles but fewer pools habitat than their controls (Bird, Sunset and Deer). Similar findings have been observed (Sullivan et at. 1987; Hogan 1986; and MacDonald et al. 1991), but in most instances change occurs from the removal of LWD or increase of sediment loads which fill pools. Although bedload deposition may have filled pools it cannot be inferred from my data.

In Bird, Sunset, and Deer Creeks (all logged), only a very small amount of LWD (10%) is stored completely within high gradient channels. As a result, pool scour may have been infrequent. Furthermore, diminished streamflow provided few areas of sufficient depth to classify as pool habitat. Only in Bird Creek does significant evidence exist that logging reduced pools. Aggradation caused formation of braided channels in reaches G-I of Bird Creek. Substrate composition is also predominately sand and silt (75%), indicating that pools may have been filled by excessive sedimentation.

Unit Type

Analysis of pool and riffle types provides no clear pattern between logged and unlogged basins. Riffle types are significantly different in all pairs, with four logged basins (Allen, Deer, Sunset and Bird) having more cascades and fewer gravel riffles. However, natural variation in channel gradient, discharge, and channel roughness are probably more responsible for riffle composition then logging. I doubt cascade frequency could increase without major channel change, for which evidence was lacking. Cascades are more likely a natural feature of high gradient streams. Bisson et al. (1982) noted that streams greater than 4% gradient have riffles dominated by cascades. Figure 6 (pg. 54) confirms this, except for Fire and Jordan Creeks whose riffles are predominately cobble above 4%.

Biological Significance

Habitat surveys provide useful, quantitative characterizations that allow resource mangers to better visualize stream channels. But as MacDonald et al. (1991) observed, our ability to classify and measure habitat probably exceeds our capability to interpret the results. My analysis shows that plunge, dammed and lateral scour pools, as well as cascades dominate habitat types. However, the question of biological importance is whether any pool type is favored by trout. Such questions are not addressed by this study, but generalizations based on literature can be related. In lower gradient reaches, pool types have a greater diversity of structural components. Gravel bars, rootwads, and streambends form more pool types, provide more microhabitat sites and potentially could support a greater abundance of age classes. In western Washington, plunge pools and dammed pools are heavily used by juvenile coho salmon, age-1 steelhead and cutthroat trout (Bissons and Sedell 1982). Lateral scour pools, with higher current velocities, are used by older trout but not by young-of-the-year salmonids (Bilby and Ward 1989). Murphy et al. (1982), also observed that trout fry used backwater pools, while trout parr prefer plunge pools and lateral-scour habitat. While such detailed information is not available in western Montana, personal experience on the Lolo N.F. while electrofishing has confirmed that species and age classes segregate according to distinct physical channel features. This study made no attempt to determine which pool type provided ideal habitat, but it is likely to assume that lower gradient reaches with more diverse pool types will support a more diverse trout population. Therefore, every attempt should be made to limit those impacts which could potentially alter stream habitat in low gradient areas.

Large Woody Debris

LWD Loading

Stream reaches near logged riparian areas usually hold more debris, with debris often consisting of smaller logs or blowdown caused by the partial removal of riparian vegetation. Three harvested basins (Bird, Deer and W.F. Thompson River) exhibit a greater accumulation of debris (4-7/100m more active debris than control streams and over 41 pieces/100m of LWD) with varying levels of riparian disturbance. Deer Creek (L) and W. F. Thompson River (L) each have over 60% riparian impacts, but Bird Creek (L) has only 37%. It then appears that debris loading is not solely dependent upon the level of riparian disturbance. I suspect that overstory composition before harvest, a stream's ability to mobilize and redistribute debris, and care taken with debris slash during logging are all responsible for debris loading.

The most severely impacted stream (Fourlakes), with over 81% of its riparian zone harvested, averages only 1 active piece/100m more than its control.

This is surprising for I would expect a heavily harvested basin to have more debris. In reality, higher debris loads are present, though they were not reflected by this survey. Most debris was too unstable to sample; only if debris provides habitat for years to come was it included in the survey. Thus, several reaches (Figure 28, pg. 149) contain an abundance of unstable debris which were not counted. This resulted in data reflecting less debris loading than is actually present and is one reason why active LWD was not significantly correlated with percent of the riparian zone harvested.

Although many variables affect debris loading, harvest units located outside the riparian zone do not. For example, Allen (L) and Sunset (L) Creeks each have similiar debris loads to their control because cutting units are on mid-slope and ridgetop positions. In fact less than 30% of either riparian zone is harvested, thus cutting units are far enough from the channel that debris entrance was rare.

Stream width and channel gradient also influence debris loading. In Deer (L) and Bird (L) Creeks, debris is longer than the channel width, which results in random accumulations of bridge and ramp pieces (Figures 29, pg. 150 and 30, pg. 151). But in the W.F. Thompson River (L) and Fourlakes (L), debris is smaller relative to the channel width and is transported throughout the channel (Figure 31, pg. 152). Each stream is larger than Deer and Bird Creeks resulting in debris jams (Figure 32, pg. 152). Therefore, it appears that in small channels debris is stable in comparison to larger channels. While debris in large channels is likely to splinter from movement in high flows, as was the case in Fourlakes.

Active and Inactive LWD

It has been widely accepted that the location, stability, and longevity of debris influences the quality of fish habitat in streams. Yet it is the arrangement of debris that controls habitat formation (Swanson et. al. 1976). Individual pieces of LWD form more pools than debris jams in most second and third order channels. Streams with less than 38% of their riparian zone harvested have similar numbers of debris per pool to unlogged stands. Moderately harvested stands (38 to 60%) average 1 to 3 active pieces per pool. Conversely, stands with 60% riparian impacts average 3 to 5 pieces of active per pool with some pools containing up to 14 pieces.

The occurrence of inactive debris is variable between logged and unlogged basins. Bird (L) and Deer (L) Creeks each have 3 to 7 more inactive debris pieces per 100 meters than their control. This is probably due to small channel widths (less transport) and high levels of riparian harvest which added debris. Other logged basins (Allen and Sunset) have 3 to 4 fewer pieces of inactive LWD per 100 meters than their controls, but it is doubtful logging is responsible because riparian harvests are not extensive. Fourlakes probably is the only stream to have inactive debris cleaned near its channel. Clearcutting occurs near the channel's edge in most reaches and downed debris may have been removed.

Potential LWD

Harvesting has reduced debris recruitment in Fourlakes (42 debris/100m less than its contro)l, W. F. Thompson River (14 debris/100m less) and Deer Creek (13 debris/100m less). In each stream logging occurs throughout the riparian zone except in steep canyons. Streams with limited riparian harvests (Bird and Sunset Creeks) have streamside logging only on first order tributaries. Thus, most riparian stands remain intact resulting in Sunset Creek having 5.5 potential debris per 100 meters less than its control and Bird Creek having 9.2 debris more than its control.

Allen Creek (L) is an exception having less potential LWD compared to its control (Crystal). Allen Creek contains 19/100m fewer potential debris than Crystal. It is not clear why fewer potential debris are present, but differences in stand composition and successional stage may have played a role. Allen Creek's riparian zone is composed of immature lodgepole pine. Crystal Creek has more mature ponderosa pine and douglas fir. Allen Creek also burned in the 1910 fire, whereas Crystal did not (Losenski, Lolo National Forest, personel communication). This may have reduced potential debris within the riparian zone causing the earlier successional stage.

Reduction of potential LWD may lead to future impacts especially in Fourlakes, W.F. Thompson River and Bird Creek. Removal of potential LWD has been shown to reduce the size of material needed for storing bedload, providing fish habitat and producing macroinvetebrates. Sedell et al (1984), concluded that fish habitat and producing macroinvetebrates. Sedell et al (1984), concluded that input of adequate size debris remains low for at least 60 years in Pacific coast streams after logging. Andrus et al. (1988), also concluded that tree growth must exceed 50 years before harvested riparian stands yield large debris in quantities matching to old growth forests. However, both studies were conducted in streams that have wetter climates and quicker rates of growth than riparian stands in western Montana. Because western Montana is colder and drier, riparian stands could take even longer to provide material of adequate size. Given that most debris in harvested basins are already showing signs of decay, I believe a time will exist when new LWD will be of inadequate size to maintain channel integrity.

LWD Diameter and Length

Logging reduced debris diameters and lengths in several streams. Debris diameters and lengths average 5.3cm/2.6m smaller in Fourlakes, 8.5cm/2.4m smaller in W.F. Thompson River and 8.9cm/3.5m smaller in Deer Creek compared to their control streams. Reduction in size is attributed directly to the abundance of slash along many clearcut channels. Slash often stayed within 100 meters of streamside harvest sites along Bird, Sunset and Deer Creeks (Figure 33, pg. 149). In larger streams (Fourlakes and W.F. Thompson River) slash moved farther downstream (Figures 34 and 35, pg. 153).

Riparian harvests ceased 15 to 30 years ago yet slash remains. Fine materials (bark, branches and twigs) are generally absent except in some pools;

however, small logs and cut stumps remain. The residence time of debris can be over 60 years in western Montana streams (Dick Kramer, Lolo National Forest, personnel communication). Keller and Tally (1979) also concluded, by dendrochronologic dates, that debris can remain in channel as long as 200 years in Pacific coast streams. Clearly, given the short duration since harvest, not enough time has passed for debris to completely decay and be removed. In only one circumstance did debris appear unstable (Fourlakes), but this is more from the abrasion of partially decayed pieces than decay itself.

In Fourlakes most reaches are clearcut to the channel, with debris rarely exceeding 5m in length and 40cm in diameter. In contrast, intact riparian stands of Fourlakes provide debris with larger diameters (41-50 cm) and longer lengths (5.1m to > 10.1m). Furthermore, the Simpson's Diversity Index shows that fewer diameter classes occur (0.50) in Fourlakes than in its control stream (0.69). It is possible that through the combination of potential debris removal and addition of slash that debris size has diminished.

In the W.F. Thompson River (Figure 36, pg. 154), reaches G-L have been harvested to the channel; as a result small diameters (7 to 1.5 cm) are abundant despite a variety of debris lengths. Figure 37 (pg. 155) reveals that pieces of LWD 0-5m long occur in all reaches except for J and L. Because of its wide channel and high flows, I believe smaller material has been transported throughout the channel. Numerous debris jams occur trapping the smaller slash material.

Not all harvested basins hold smaller debris; some contained larger material than their control. Allen Creek debris diameter and length averages 9cm/2.2m larger than its control, while Sunset Creek averages 7cm/7.2m larger. Less intense riparian harvesting added less debris to channels in Allen and Sunset Creeks than other logged basins. Therefore, natural variability is probably more responsible for size differences than logging's effect.

Debris size is also significantly smaller in pools of streams subjected to intense riparian harvests, with pools averaging 8cm and 3.6m smaller in debris diameter and length. In time this debris will become unstable and more prone to movement than naturally occurring pieces. When debris is stable its capacities for pool anchoring, cover, and substrate storage are enhanced. If, however, it becomes unstable, these function will be diminished (Bryant, 1983). Presently most pools (60-80%) are formed by debris in impacted reaches of Bird and W.F. Thompson River. In an extreme peak flow, debris could be transported downstream causing a reducing the number of pools.

In Fourlakes LWD forms 30% of all pools. This is a much smaller proportion than than its control or other surveyed streams in the area. Pools formed by LWD may have already been reduced leaving only stable pool creators such as bedrock and boulders to take its place. In Deer Creek streambend pools dominate, not LWD pools. Therefore, smaller debris may not decrease pool frequency. In addition, the channel is small enough that remaining potential debris, even though shorter in length, would be of sufficient size to replace decayed material.

LWD Formation

Debris formation is more dependent on channel width, debris length, and random debris entrance than logging itself. Only two logged streams give any indication that debris formation has been altered. As with other debris parameters, Fourlakes and W.F. Thompson River consistently show that the addition of slash and the removal of potential debris alters LWD stability. Each stream has channel/debris proportions of 0.91 and 0.76 respectively, meaning that debris length is similar to channel width. In both streams 64% of LWD exists in unstable formations. This is consistent with the findings of Bilby (1984), who found that debris length was the most important component to debris stability.

In contrast, streams with bridged pieces average channel/debris proportions of 0.17-0.48. Most smaller streams [Crystal (U), Allen (L), Lupine (U)] fall into this range. Even Bird and Deer Creeks, with their excessive debris loading, fall into this range. Thus, relatively short pieces of debris can be stable in narrow channels, and the impact of debris slash will vary from stream to stream. This is one reason why impacts from unstable debris are less frequent in Deer and Bird Creeks than in Fourlakes and W.F. Thompson River. While narrow channels have similar formation types to their controls, it must be noted that most of this material is from slash and not natural debris. Unlogged basins generally have more material with branches and portion of the rootwad. From a fish habitat standpoint, this material will material provides greater hydraulic diversity and cover than fragments of stems and limbs (Bisson et al. 1987).

Substrate

Substrate Composition

Hydrologic investigations have shown that forest roads are principle contributors of stream sediment (Meehan, 1991). Because not all heavily roaded basins hold more fines, there is no clear indication that roads solely contribute fine accumulation. For example, Deer Creek (L) has a road density of 6.6 mi/mi^2 and averages 54% higher in pool fines than its control. The W.F. Thompson River (L) has 4.5 mi/mi^2 of roads and averages 13% higher in pool fines than its control. Fourlakes (L) averages 6% higher in pool fines than its control and has a road density of 3.6 mi/mi^2. However, not all heavily roaded streams contain more pool fines. Sunset (L) has a 5.0 mil/mi^2 road density but averages 4% less in pool fines than its control. In addition, Bird (L) averages 1% higher in pool fines than its control, yet has a road density of 3.5 mi/mi^2. Therefore, it appears that road density alone may not contribute to pool fines. A basin may have a high road density, but if most roads are on ridge tops sediment delivery will be low. I feel that road location close to perennial and intermittent channels, and erodible landtypes plays a greater role in channel sediment delivery.

As mentioned earlier, the pebble count technique underestimated the sampling of smaller particles. MacDonald et al. (1991) noted that pebble counts are simple and rapid, but there may be some bias against selecting very small particles. Therefore, I feel fines were not accurately sampled. For example, both Sunset (reaches E-J) and Bird Creeks (reaches B, C, G-I) have high levels of sedimentation reported in the field notes. Fines often composed of 20-50% of the total pool surface area, yet due to the pebble count technique a lower fine sediment value was recorded.

A second problem was very high stream gradients (9-15%). Cederholm, et al. (1982), found that significant amounts of fines in spawning gravels were overlooked unless gradients were below 4%. My lowest gradient stream, Lupine (U) (3.8% gradient), averages a 27% fine composition in pools, but other streams with higher gradients never average above a 19% fine composition. Only Deer Creek (L) (9.9% gradient), has a higher pool fine composition of 73% than Lupine, but this is because pools occur only below a 5% gradient. Therefore Deer Creek's fine composition is more reflective of a low gradient stream.

On occasion, fines occur in higher gradient reaches. Several streams [(W.F. Thompson River (L), Fire (U) and Bird (L)] hold more fines in gradients of 5.0%-12.5%. Numerous debris jams in both Bird and W.F. Thompson River (Figures 32, pg. 152 and 38, pg. 156) and a new road near the main channel in Fire Creek

(Figure 39, pg. 156) appear to be responsible. Thus, when fine deposition is recent or if LWD is available to store fines, increased fine accumulation occurs.

The last circumstance that may have lead to lower pool fines is time. Most road construction ceased 15-25 years ago, so initial sediment would have been transported downstream to lower gradient channels. If sedimentation continues it probably occurs at a lower magnitude than when construction took place. WATSED predicts that Sunset, Deer, Fourlakes and W.F. Thompson River all have sediment inputs of 228 to 372 percent above natural as of 1992 (Table 15, pg. 88). Pool fines are also higher in these streams than their control, with the exception of Sunset Creek. While percent above natural can not be used as an absolute value, due to lack of model validation, it does imply that roads continue to add fines.

Substrate for Redds

Cummins' (1974) extensive literature review found that no single factor has greater biological significance than the type of substrate. Optimum spawning substrate appears to be gravels containing small amounts of fine sediment as well as small rubble to support egg pockets (Beschta and Platts, 1986). The Nez Perce National Forest Methodologies (U.S.F.S., 1991a) indicate that resident trout commonly use small (0.6-2.5 cm) and coarse (2.5-7.6 cm) gravels during redd formation. Larger fluvial trout use a slightly larger particle size (7.6-15.2 cm) in addition to the smaller particles.

Surveyed riffles average 39 to 79 percent of total substrate composition for particles 0.6 to 7.6 cm in size. Harvested basins have slightly more small gravel than unlogged basins (Table 17, pg. 90). Coarse gravel did not vary significantly within any pairs. All streams have an abundance of particles 0.6-7.6 cm, therefore logging has probably not caused a decrease in material needed for redd formation. However, proper particle size alone does not produce the ideal redd. Redd location in relation to water velocity, water depth, and cover should also be considered if adequate comparison of available redd gravel is to be made.

Channel

Channel Impacts

Evidence suggests that timber harvests can affect the volume, rate and timing of water, and sediment passage through a basin (Grant, 1988). Changes in water and sediment can lead to channel aggregation, widening, streambank failures, and pool reduction. Detection of change can be difficult, especially if changes are subtle. Detection of change is further complicated by variations in channel scour, channel roughness, bank material, valley confinement, and gradient to name only a few variables.

WATSED predicted that harvested basins average a higher water and sediment yield over natural than unharvested basins (Tables 15, pg. 88 and 19, pg. 97). It also predicted that most streams (except Deer and Fourlakes) have similar natural water yields (Table 19, pg 100). However, while basins are matched to be as similar as possible, I can not infer stream morphologies are also similar. Therefore, I can only suggest through the consistency of pair differences that change has occurred.

Analysis revealed that most channels in harvested basins are significantly and consistently wider than in unharvested basins. Channel width can widen when changes in sediment and water occur. Aggradation of sediment can raise channel bed elevation, cause channel braiding, and divert flows into banks causing them to widen. Channel scour of sediment can also lead to bank steepening, instability, and widening. Grant (1988) noted increases in channel width from increased peak flow that removed bank material. Therefore, since both degradation and aggradation can widen channels, it is difficult to tell which process controls channel dimensions. However, because pool area is larger, riffle area is of equal size, and number of pools per 100 meters are similar in logged and unlogged basins, significant aggradation by bedload is unlikely.

Evidence suggets that channel width remains unchanged from preharvest levels. First, channel LWD was not removed. Thus, an important component of channel stability would remain unaffected and bedload retention and reduction of peak flow potential energy would continue. Second, channels are located in very narrow valleys and bank material is composed of resistent residual bedrock, alluvial or colluvial deposits. Thus the channel is resistant to erosion and would be difficult to significantly enlarge. Furthermore, eroding banks are infrequent suggesting that channels have either stabilized within the last 10-20 years or that eroding banks never were frequent. Only where riparian harvests removed streambank trees is obvious that channel width enlarged (Figure 40, pg. 157). This is because rootwads are no longer able to bind bank material.

Because channel banks are well armored, overhead bank cover is limited. Hence an important fish cover component is lacking in most surveyed streams. Overhead bank cover is generally more prevalent in pools than in riffles (Table 27, pg. 158). Overhead cover ranges from 5.6% to 56.1% of the linear bank distance in pools and 1.1% to 31% in riffles. A possible explanation why pools have more overhead cover is that pools are areas of greater scour at high flow. Hence, more material is scoured from banks causing more undercut banks to form.

As mentioned previously, WATSED analysis predicted water yield increases in all harvested basins. However, I feel the degree of increase is not sufficient to change channels. Most harvested basins contain larger pools, suggesting that higher stream flows may have increased pool scour. Yet the link between a change in pool size and water yield is not an easy one to make. Pools can vary in shape and size according to obstruction characteristics, degree of channel constriction, and horizontal deflection angle (Beschta and Platts 1986, Sullivan 1987, Lisle 1986). Consequently, natural variation, may be as responsible for pair differences as is harvesting.

Two of four streams having larger pools naturally have higher water yields as predicted by WATSED. In Deer Creek (L) water yield averages 2277 AF (acre-feet) higher and in Fourlakes Creek (L) 5296 AF higher than in their control streams. Other pairs average no more than a 679 AF difference (Table 19, pg. 97). Thus, streams that carry more water annually, naturally have larger channels to accommodate their given flow.

To my surprise, harvested basins have deeper riffle habitat. Measurements were taken during low flow, therefore consistent increases in depth may indicate an increase in base flow. Logging has been shown to increase streamflow if extensive canopy removal takes place (Meehan, 1991). Yet, studies in drier snowmelt—dominated areas of the Rocky Mountains have shown low flow increases of only 12% following logging (Troendle, 1983).

I doubt base flow has increased for the following reasons. First, base flows in the Pacific Northwest commonly recover in 10 years after harvest (MacDonald, et al. 1991). Harvested basins of this study have had double this time for some hydrologic recovery to occur. Second, several harvested basins have naturally higher water yields; therefore it is possible they also have deeper base flows than their controls. Finally, although riffles are significantly deeper, pools are not. If base flow increased, I would expect pools to be deeper, deeper, since they hold more water at low flow than do riffles.

Riparian

Riparian Impacts

Riparian vegetation influences stream ecosystems. In addition to contributing leaf detritus, riparian vegetation produces insects, contributes logs and branches that shape channels, and provides essential cover for salmonids (Meehan, 1991). Riparian disturbances can have profound effects on fisheries. Monitored streams show signs that significant disturbances have taken place. Riparian harvests have led to immature successional stages, diminished canopy closures, and altered overstory compositions.

Changes in riparian canopy closure occurs where harvest: (1) removed overstory cover, (2) changed overstory composition or (3) caused extensive blowdown. Riparian stands with over 60% of their area logged average 33 to 49% less canopy closure than their controls. Riparian stands with 20 to 35% disturbance average 14 to 35% less closure or have slightly greater closures of 10%. The increased sunlight made available by harvesting promoted rapid growth of understory growth species such as dogwood, alder, and willow. However, increased understory growth did not provide comparable canopy closures to species that were present before harvest.

A loss of mature trees potentially may affect future LWD recruitment and channel stability. First and second order channels are particularly dependent upon LWD for pool formation, reduction of potential energy, and sediment storage. Unfortunately, first and second order channels have the greatest degree of successional changes in logged basins. Figures 41-45 (pgs. 159-163) show that the W.F. Thompson River (reaches F-I, K), Fourlakes (reaches G-H), Deer (reaches H-J), Sunset (reaches I-J), and Bird (reaches F-K, N, O) each have altered successional stages in headwater channels. At the present time ample LWD is available; however, debris already shows signs of decay and instability. In the future, potential debris may be unavailable or of insufficient size to replace existing material. This may result in more extensive channel changes and fishery impacts.

Riparian harvests can also change allochthonous sources of organic matter for streams. Streamside logging often switches litter type that enters streams from mostly conifer needles under mature forest, to deciduous leaves in early successional stages (Meehan 1991). Such changes occur in harvested streams where alder became the dominate overstory after streamside logging. Therefore, changes in litter type may have increased macroinvertebrate communities, especially shredders. Yet in most circumstances overstory changes occur in first order channels where fish habitat and fish are lacking to directly benefit from the increased productivity.

Temperature

Stream Temperature

Logging appears to have little or no effect upon stream temperatures 15 to 30 years after harvest. Even though several streams still have reduced canopy cover, temperatures differ by no more than 4.3°F. This is a far smaller increase than Beschta et al (1987) found when complete canopy removal occurred in the Pacific Northwest. Increases of maximum temperatures were shown to be 3 to 8°C, which was due almost entirely to the additional solar radiation. Brown and Krygier (1967) also concluded that stream temperatures are directly proportional to surface area and solar energy input, but in addition they showed that temperatures are reflective of topography and the inflow of surface water and groundwater.

There are several reasons why temperature differences of streams in this study are not more pronounced. First, 15 to 30 years have passed since logging ceased; long enough time for streamside vegetation to regenerate. In Allen, Deer, Fourlakes and W. F. Thompson River, regrowth occurred very rapidly on moist sites. In fact, Brown and Krygier (1970) found that summer maximums decreased to prelogging levels within six years because of the vigorous regrowth of alder, salmonberry, and elderberry. Yet, even though regeneration has taken place, canopy closure is still lower for Deer, Sunset, Bird, Fourlakes and W. F. Thompson River than for control streams. It then appears that reduced canopy closure has no lasting effect on stream temperature. The only effect of a reduced canopy closure has been to cause greater fluctuation in maximum temperatures. All logged basins with lower canopy closures (except Fourlakes) have greater standard deviations for summer maximums than their control.

The second reason why temperatures are similar resulted from sampling design and frequency. The first summer max/min thermometers enabled me to detect temperature variation, eliminate temporal variability and maintain a biweekly sampling frequency. However, this schedule did not provide enough data to identify trends or make differences statistically significant. A closer sampling period would have allowed for more data to better indicate temperature changes.

During the second field season, four thermographs eliminated some biweekly sampling because readings were continuous. Unfortunately, I did not obtain enough thermographs to monitor all streams and had to again use max/min thermometers. Thus, I ended up with eight streams using biweekly measurements and four streams with continuous data.

Impacts to Salmonids

Salmonids are coldwater fish with definite temperature requirements. Salmonid egg and alevin development, and subsequent timing of emergence from gravel, have been shown to be closely associated with stream temperature. Monitored stream temperatures appear to be within the optimal range 12 to 14°C (54 to 58°C) for salmonids (McDonald, et al. 1991). However, several streams (Deer, Bird and Crystal) have maximums above 60°F (15.8°C).

As mentioned previously, most streams contain westslope cutthroat trout (Salmo clarki). In addition, Lupine (U), Deer (L), Bird (L) and Fire (U) Creeks support brook trout (Salvelinus fontinalis), while only the W. F. Thompson River (L) and Spruce (U) Creeks support bull trout (Salvelinus confluentus). Table 28 (pg. 164) shows species composition from the limited presence/absence electrofishing survey.

Bull trout are found only in the Thompson Falls area where temperatures ranged from 37 to 51°F (3 to 10.5°C). Pratt (1984) found that preferred temperatures are 41 to 54°F (5 to 12°C) and spawning temperatures are 48 to 50°F (9 to 10°C). Monitored temperatures thus verify the preferred range Pratt found and suggest that bull trout occupy only streams with the coolest temperature regimes. This may be due to high proportions of snow melt water and and cold groundwater.

Brook trout occur where temperatures range from 38 to 65°F (3.5 to 18.3°C) and average 41.6 to 57.1°F (5.0 to 14.0°C). Preferred temperature ranges for brook trout are 50 to 54°F (10 to 12°C), while tolerable ranges are 32 to 68°F (0 to 20°C) and lethal temperature is 80°F (29.8°C) (Meehan, 1991). Monitored temperatures are certainly within preferred ranges, but the higher temperature peaks found in Deer and Bird Creeks (>60°F) may cause stress to brook trout if they are of long duration.

Cutthroat trout are widespread, thus are exposed to a wide range of temperatures 37 to 57°F (3 to 13.8°C). Griffith (1986) reported that westslope cutthroat prefer temperatures of 41 to 56°F (5 to 13°C). Meehan (1991) found that spawning temperatures commonly occur at 43 to 65°F (6.1 to 17.2°C) and lethal temperature is at 73°F (22.8°C). Thus it appears that harvested basin water temperatures pose no threat to westslope cutthroat because all monitored streams are well within the preferred range.

Parameter Evaluation

Ideal parameters should be highly sensitive (responsive), accurate, and easy to measure. Unfortunately not all parameters used met these criteria, nor did they all provide statistically significant results. In this section I will inform future researchers about which parameters were statistically sensitive, repeatable, and least difficult to collect.

A parameter may or may not be statistically significant for a number of reasons: sample size, variability within the monitored population, and sensitivity of the parameter to detect an impact or absence of an impact. To determine causes of significance or lack of significance is a Master's project in itself. Therefore, only the distribution of P-values and parameter consistency will be examined.

The paired t-test played a critical role in analyzing basins with similar physical characteristics. Because basins were matched, the paired t-test was a more powerful test to use than the two-sample t-test, since it took into account pair-to-pair variability. Consequently, statistically significant variables indicated by the paired t-test may be responsive enough to monitor logging disturbance. More importantly, the test would indicate which variables are least sensitive to showing change. Of course this inference has its limitations because variable sensitivity is influenced by sample size, natural variability and level of disturbance encountered.

Figure 46 (pg. 168) shows the distribution of paired t-test p-values, and Table 29 (pg. 165) illustrates variable trends. Seven of twenty two variables are statistically significant at the 0.05 alpha level. Pool and riffle widths, riffle depths, and pool areas are significant and consistently larger in logged basins. Harvested basins also have significantly more active LWD, less potential LWD, and a lower density of canopy closure. Because these variables are significant and consistent they may be sensitive enough to be used as indicators of change.

Table 30 (pg. 166) reveals that variable polarity was similar between both the paired and two-sample t-tests. This is to be expected because similar means are being tested. The only difference is sample size because the two-sample t-test analyzed individual observations, not paired observations. P-value distributions vary considerably in Table 30 (pg. 166). For example, variables with a small sample size (less than 10 degrees of freedom: maximum and minimum temperature, eroding banks, overhead cover and overhanging vegetation) have p-values between .10 - .20. These variables show no distinct polarity to clearly differentiate logged from unlogged basin means. Only potential LWD and canopy closure, with degrees of freedom less than 10, show a significant and consistent pattern. This agrees with the results of the paired t-test.

Other variables listed in Table 30 have larger sample sizes (dfs of 30-200) and a greater level of significance. This is anticipated because larger samples will increase the likelihood of finding significance. However, even though significance increases, polarity does not. Most channel and LWD variables have at least 5 values below the 0.05 alpha level, yet the values are evenly split between the logged or unlogged basin being larger. Only pool and riffle width, pool area and riffle depth show a significant and consistent pattern. This agrees with the paired t-test results and again suggests that these variables may be more responsive to indicating a change.

Table 31 (pg. 167) shows the distribution of chi-square p-values. Unlike t-test p-values, chi-square values are categorical and thus show no numeric pattern between logged and unlogged basins. LWD formation, riparian overstory composition, successional stage and riffle type all are significant at the $\alpha = 0.05$ level in at least four of six pairs. However, as mentioned throughout my thesis, natural variability or lack of disturbance often made it difficult to find a consisten pattern among the chi-square residuals. Only successional stage and overstory composition clearly show a consistent pattern between logged and unlogged basins. Hence, interpretation of significance must be made only when considering all available information that substantiates a logging impact has occurred.

Replication

All measurements are subjective to some degree and thus may be difficult to reproduce. It is hoped that by making enough measurements an observer can quantitatively determine a stream's condition. Future researchers may or may not be able to duplicate my results because streams change. They experience seasonal and catastrophic events which adds natural variability on to already subjective measurements.

Parameters based on seasonal fluctuations will be difficult to reproduce. For example, I measured channel width using the wetted width which is dependent on water depth. Therefore my width measurements are really a snapshot in time and will be difficult to use as a long-term monitoring tool. Other dimensional parameters (depth, max depth, length, area, pool/riffle ratios) will also vary to some degree.

Categorization of pool types may also be difficult to duplicate, for the classification system did not account for all habitat features. Nine pool types were used, but I still encountered pools that did not fit into a category. Pools with multiple creators were a particular problem. For example, pools in low gradients (< 5.0%) are often created by streambeds, LWD, and rootwads. Hence the pool has backwater, dammed and scoured characteristics. In this circumstance a subjective choice was made and it is this choice that will be difficult to reproduce. In most reaches, pool types should be reproduceble because streams have only 2-3 pool types. This is because stream gradients are above 9% with pools being either plunge or dammed. But in low gradient streams, with more pool formative features, duplication will not be as easy.

Difficulty in Collection

Most parameters were easy to measure and record. The greatest difficulty proved to was keeping track of what to collect and when intensively sampled habitat would occur.

Of the 32 parameters collected two were difficult to sample. Active and inactive LWD were tallied over the entire surveyed stream length. It soon became tedious keeping count of LWD while measuring other parameters and categorizing habitat. A handcounter with two individual counters would have made it easier to tally active/inactive pieces and concentrate on other parameters.

Defining pools in first order channels was also difficult. In Deer and Sunset Creeks, water depths sometimes became too shallow (<15 cm) to classify pools. If pools were classifed, I feel microhabitat would have been surveyed, increasing my survey intensity. The Western Division American Fishery Society (1987) defines pools as having reduced current velocity, water deeper than the surrounding areas, and is usable by fish for resting or cover. Unfortunately, water in first order channels was too shallow for cover, thus the pools were excluded and recorded as pocket water. This in turn decreased pool frequency and sampling intensity. As a result intensity. As a result, a lack of intensive information on pools was collected.

Therefore I suggest that high gradient channels, have measurement intensity for pools increased from 10 to 20 or 30%. This should not increase time sampling because pools are comparatively rare, but this will provide more accurate information on pool characteristics.

Figure 26. Woody debris slash in the W.F. Thompson River

Figure 27. Woody debris slash and blowdown in first order channel of Bird Creek

Figure 28. Unstable LWD in Fourlakes Creek

Figure 33. Debris slash in first order channel of Sunset Creek

Figure 29. Bridged LWD in Bird Creek

Figure 30. Ramped debris in Deer Creek

Figure 31. Transported debris in Fourlakes Creek (top)

Figure 34. Transported slash in Fourlakes Creek

Figure 35. Transported debris in W.F. Thompson River

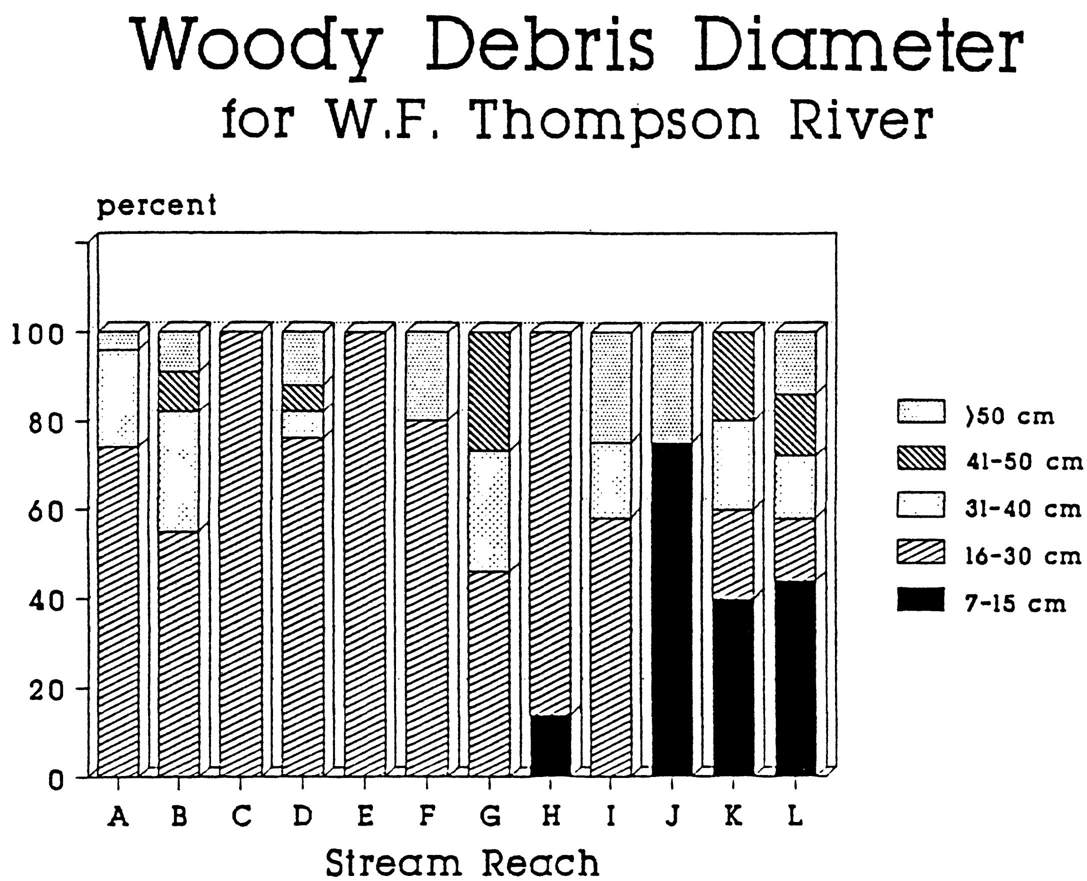

Figure 36. Reaches near logged riparian zones with small diameter debris

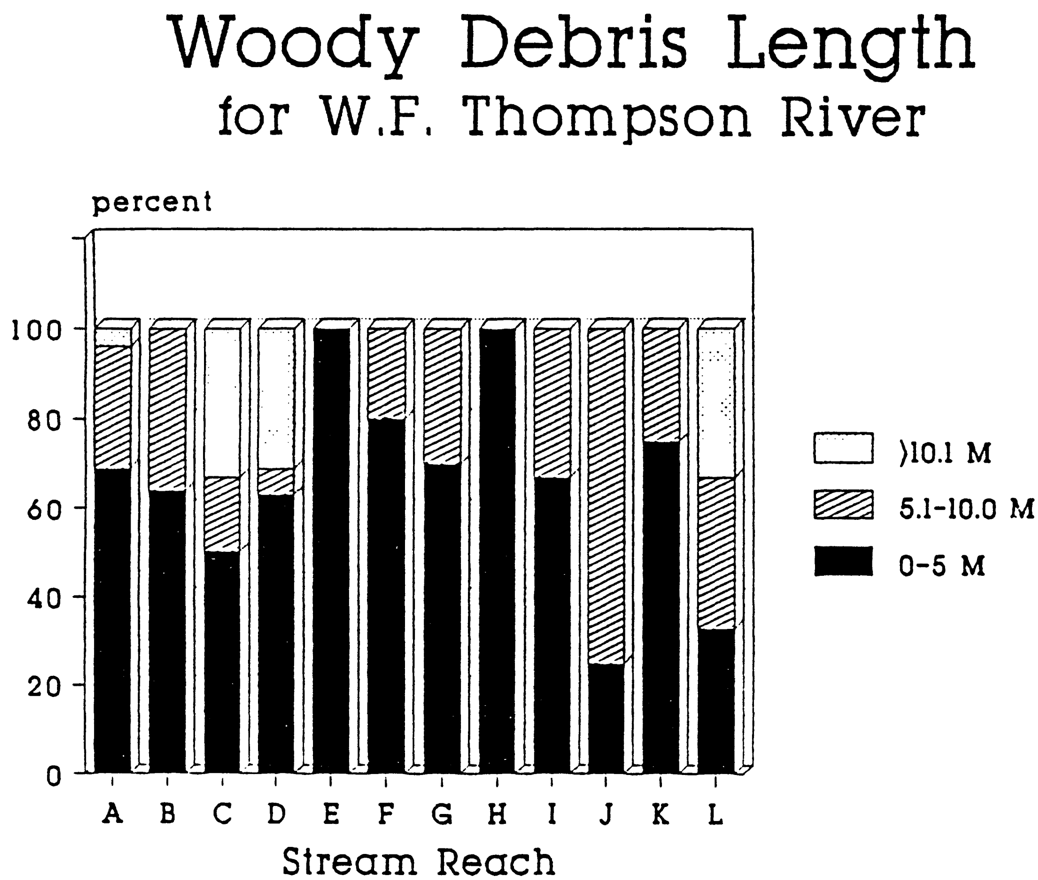

Figure 37. Occurrence of shorter debris lengths in the W.F. Thompson River

Figure 38. Stored fines behind LWD debris jam

Figure 39. New road in Fire Creek near side channel

Figure 40. Eroding banks caused by riparian harvesting

Table 27. PERCENT OF OVERHEAD BANK COVER BY HABITAT TYPE WITHIN PAIRED STREAMS

STREAM	POOLS	RIFFLES	GLIDES
CRYSTAL (U)	5.6	6.3	0
ALLEN (L)	21.1	9.8	7.5
LUPINE (U)	50	17.5	0
DEER (L)	17.9	24.3	30.2
JORDAN (U)	11.9	1.5	9.3
SUNSET (L)	37.9	7.5	0
FIRE (U)	16.5	6.1	0
BIRD (L)	47.5	31	0
SPRUCE (U)	23.6	12.6	0
FOURLAKES (L)	32.3	1.7	11
HONEYMOON (U)	56.1	9.3	0
W.F.THOMPSON (L)	14.4	1.1	3.8

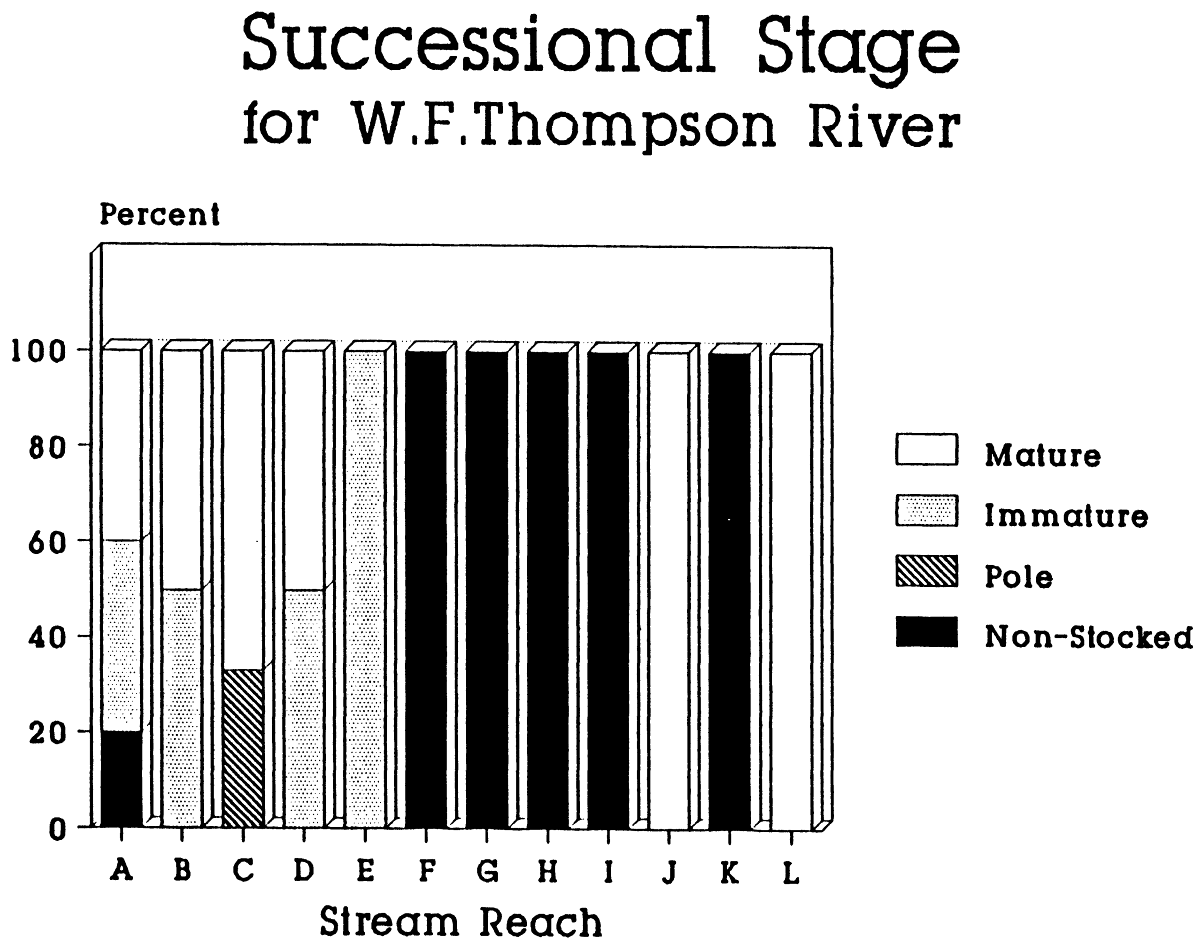

Figure 41. Ealier successional stages caused by streamside logging.

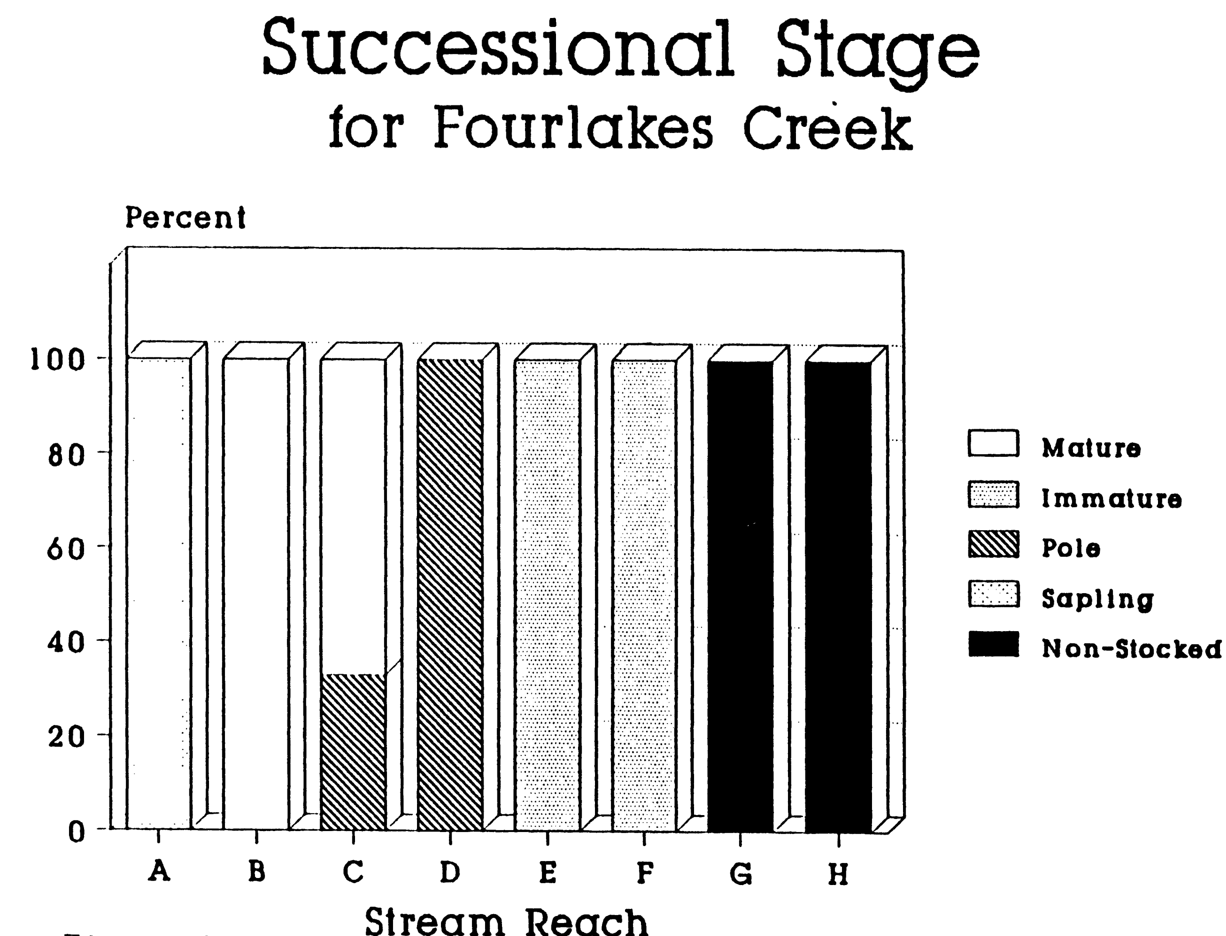

Figure 42. Successional changes caused by streamside logging in Fourlakes Creek.

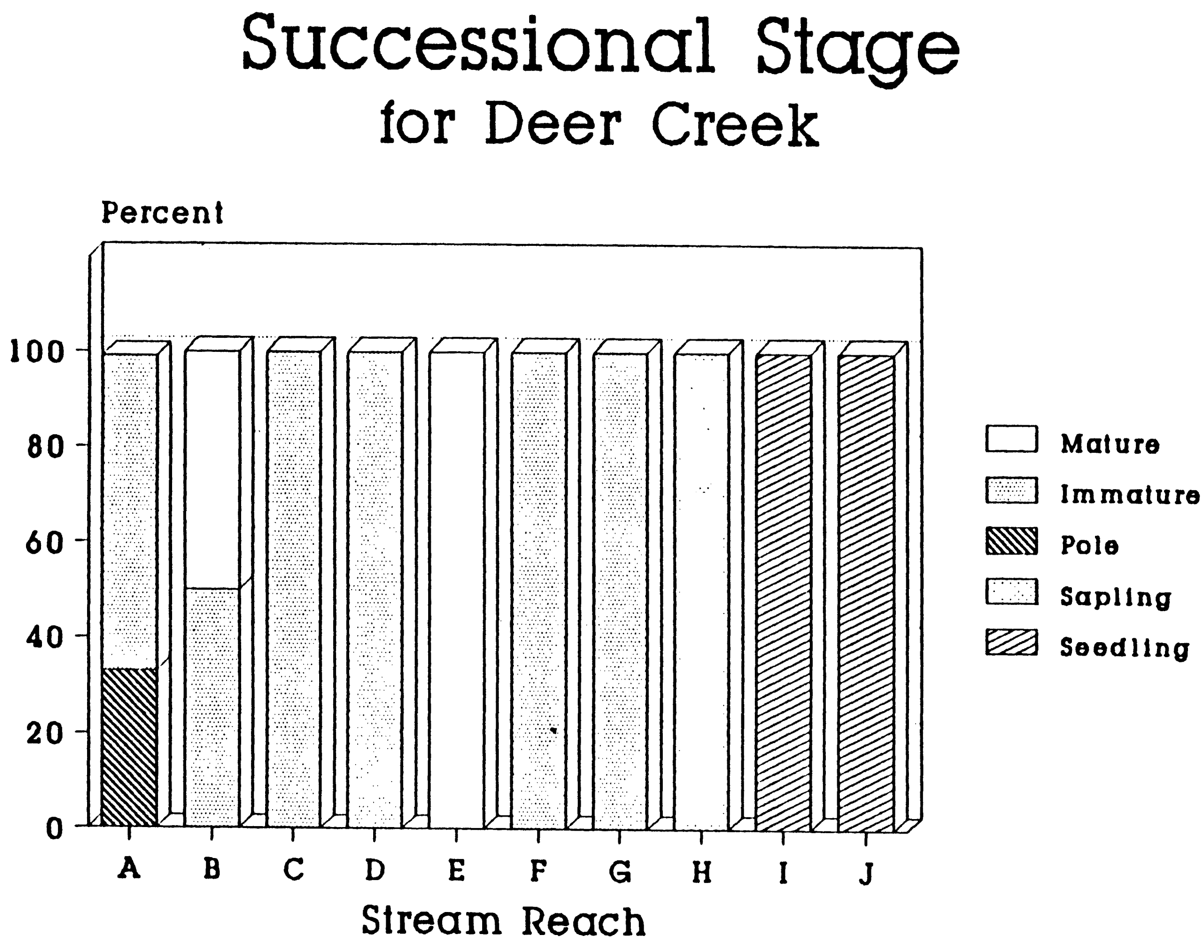

Figure 43. Successioanl changes caused by streamside logging in Deer Creek.

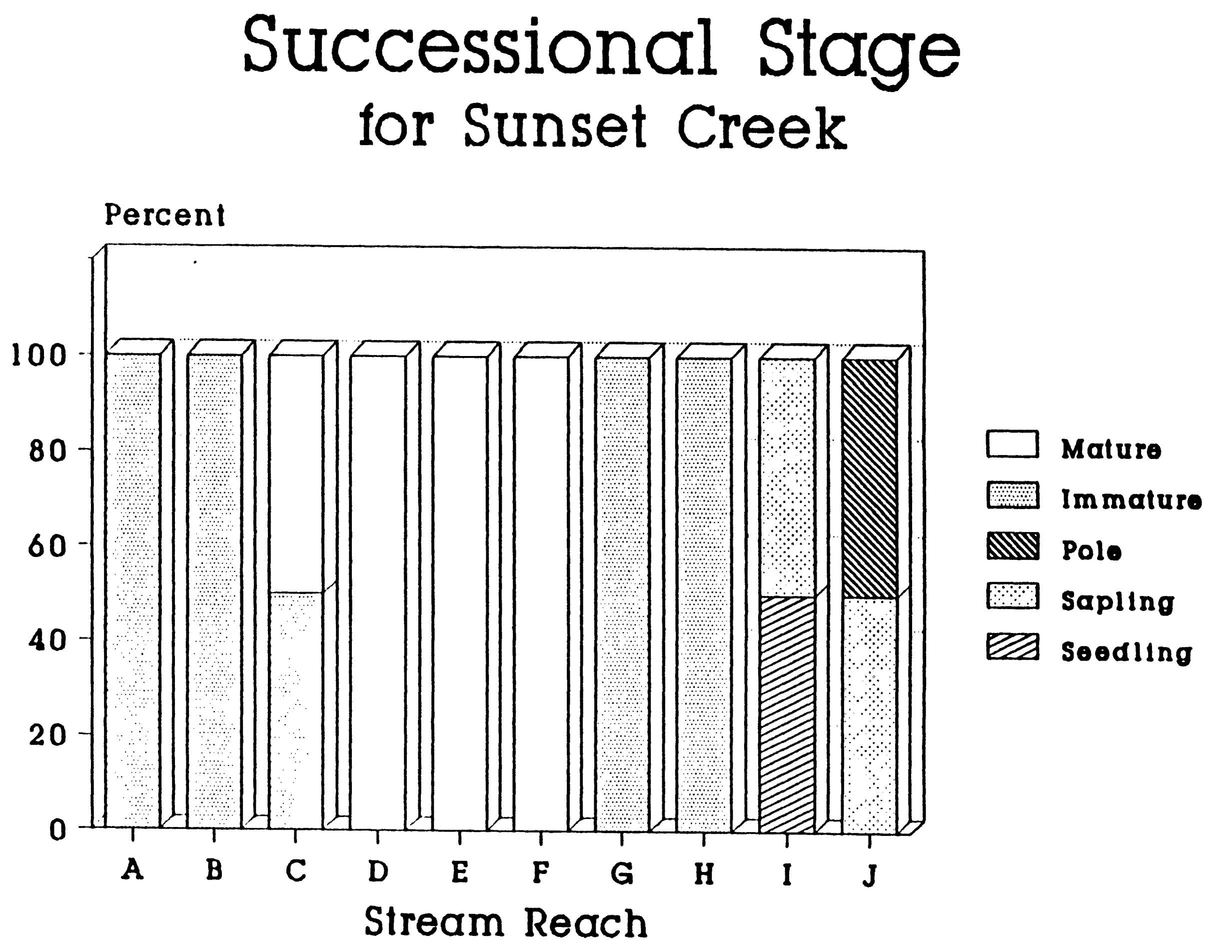

Figure 44.. Successional changes caused by streamside logging in Sunset Creek.

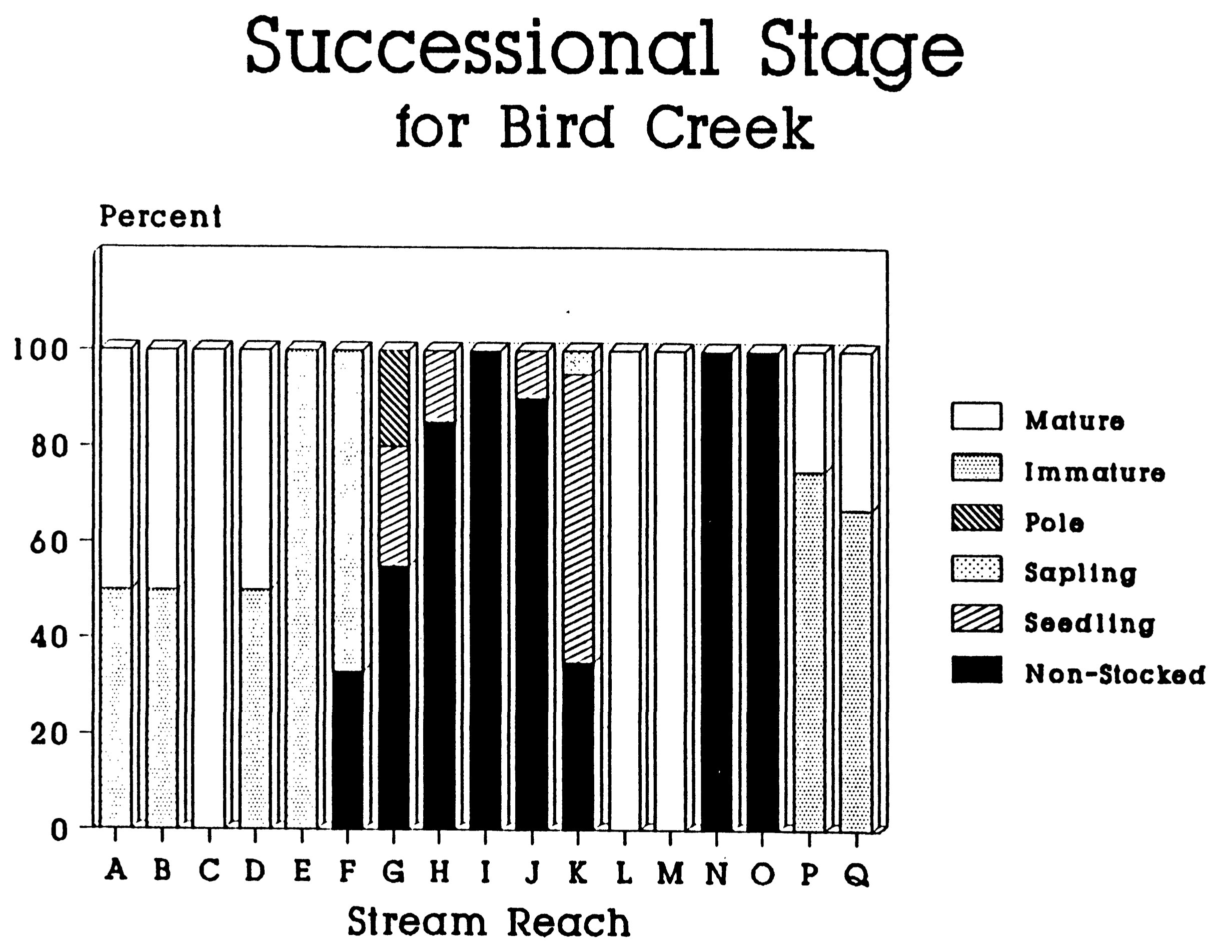

Figure 45. Successional changes caused by streamside logging in Bird Creek.

Table 28. SALMONID COMPOSITION WITHIN PAIRED STREAMS

STREAM	WESTSLOPE CUTTHROAT	BULL TROUT	BROOK TROUT
CRYSTAL (U)	100	-	-
ALLEN (L)	100	-	-
LUPINE (U)	25	-	75
DEER (L)	15	-	85
JORDAN (U)	**	**	**
SUNSET (L)	**	**	**
FIRE (U)	68	-	32
BIRD (L)	16	-	84
SPRUCE (U)	70	30	-
FOURLAKES (L)	100	-	-
HONEYMOON (U)	100	-	-
W.F.THOMPSON (L)	37	63	-

ALL VALUES IN PERCENT
**NO FISH FOUND

TABLE 29.

SUMMARY OF P-VALUES

FROM PAIRED T-TEST

SIGNIFICANCE	LOGGED> UNLOGGED	UNLOGGED> LOGGED
S	POOL WIDTH	CANOPY CLOSURE
S	RIFFLE WIDTH	POTENTIAL LWD
S	RIFFLE DEPTH	
S	POOL AREA	
S	ACTIVE LWD	
NS	POOL LENGTH	#POOLS/100M
NS	POOL MX.D	LWD DIA
NS	RIFFLE MX.D	INACTIVE LWD
NS	ERODING BANKS	
NS	OVERHEAD COV.	
NS	RIFFLE AREA	
NS	OVERH. VEG.	
NS	LWD LENG	
NS	MAX TEMP	
NS	MIN TEMP	
NS	RIFFLE LENGTH	

NS(NOT SIGNIFICANT)
S(SIGNIFICANT AT 0.05 ALPHA LEVEL)

TABLE 30. **DISTRIBUTION AND POLARIZATION OF P-VALUES FROM COLLECTED VARIABLES**

VARIABLE	UNLOGGED > LOGGED					LOGGED>UNLOGGED				
	<.05	.05-.10	.10-.15	.15-.20	>.20	>.20	.20-.15	.15-.10	.10-.05	<.05
POOL AREA	2	0	0	0	0	0	0	0	1	3
RIFFLE AREA	2	0	0	0	0	1	0	0	0	3
R. LENGTH	1	0	0	1	0	2	1	0	0	1
R. DEPTH	0	0	1	0	0	1	0	0	1	3
R. MX DEPTH	1	0	0	0	0	1	1	0	0	3
R. WIDTH	0	0	0	0	0	1	0	0	0	5
POOL LENGTH	2	0	0	0	0	1	0	0	0	3
P. DEPTH	1	0	0	0	0	1	0	0	0	3
P. MX DEPTH	1	0	0	0	0	1	0	0	0	3
P. WIDTH	0	0	0	1	0	0	0	1	1	4
#POOLS/100M	2	0	1	0	1	0	1	0	0	1
LWD DIA	2	1	0	0	0	0	1	0	0	2
LWD LENG	2	1	0	0	1	0	0	0	0	2
ACTIVE LWD	0	0	0	0	0	3	0	0	0	3
INACTIVE LWD	2	0	0	0	1	0	0	0	1	2
POTENTIAL LWD	3	1	0	0	0	0	1	1	0	0
OVERH. VEG	0	1	0	0	1	1	2	0	0	1
OVERH. COV	0	1	0	0	0	2	1	0	0	2
ERODING BANKS	0	1	0	0	0	1	1	1	1	1
CANOPY CLOSURE	5	1	0	0	0	0	0	0	0	0
MAX TEMP	1	1	0	0	0	1	0	0	2	1
MIN TEMP	1	0	0	0	1	2	1	0	1	0

TABLE 31.

DISTRIBUTION OF CHI-SQUARE P-VALUES

VARIABLE	<.05	.05-.10	.10-.15	.15-.20	>.20
LWD FORMATION	4	0	0	0	2
RIP. OVERSTORY	5	0	0	0	1
RIP. UNDERSTORY	3	0	2	0	1
SUCC. STAGE	4	0	0	1	1
UNIT TYPE	2	0	0	2	2
POOL TYPE	2	1	0	0	3
RIFFLE TYPE	6	0	0	0	0
STRUC. ASSOCIATION	1	3	0	0	2
POOL SUBSTRATE	3	0	2	0	1
RIFFLE SUBSTRATE	1	1	1	0	3

DISTRIBUTION OF P-VALUES
FROM PAIRED T-TEST

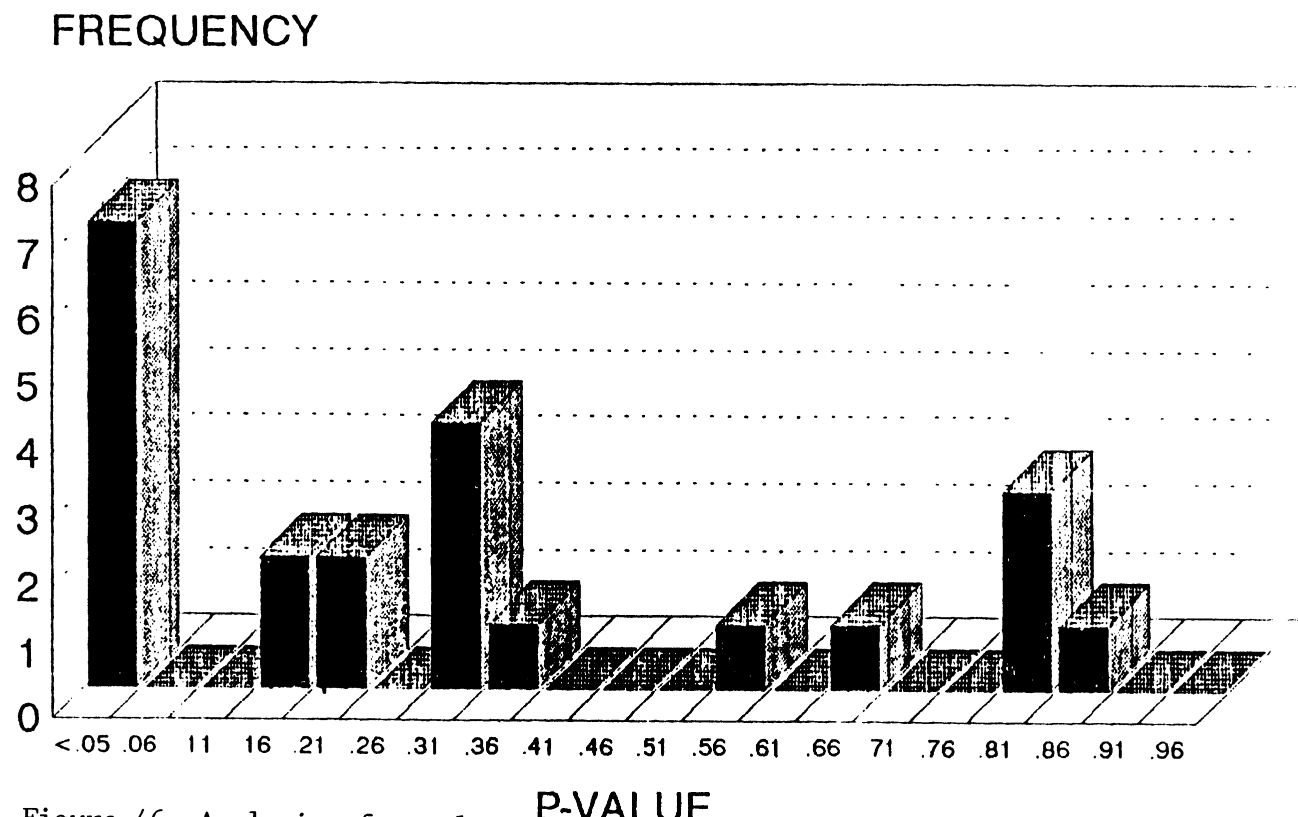

Figure 46. Analysis of p-values from paired t-test

SUMMARY AND CONCLUSION

Logging had little to no impact upon pool formation material, pool and riffle frequency, or habitat types 15-30 years after harvests. However the immediate impacts after logging will never be known. Habitat diversity did not decline with greater watershed disturbance. Harvested and control basins are very individualistic in the types of habitat and pool structural associations present. Several harvested basins contain fewer pools than their controls, but differences in channel gradients and water depths are responsible. Habitat remains unaffected because channels were not cleared of LWD, gradients are too high for significant sediment storage, water yields were insufficient to cause channel changes, and structural controls are very stable.

The lack of significant impacts suggests that habitat types and structural controls may be sensitive only to intense riparian or channel disturbances that decreased bank stability, increase sediment and water yields, or alters the functional role of LWD. Lower gradient habitats may be more responsive to logging impacts because sediment is likely to fill pools.

Large woody debris varies considerably between logged and unlogged streams. Stream width, riparian successional stage, overstory composition, and riparian harvests influence LWD characteristics. Impacts to LWD were minor because debris was not removed; thus, debris at the time of harvest would remain unaffected. Overall, harvested streams contain more active LWD, less potential LWD, but similar LWD lengths, diameters, and inactive debris densities compared to control streams. Debris formation was unaffected, except in those streams with greater than 60% of their riparian zone logged.

Based upon observations and resulting data, two levels of impact can be recognized. Streams with over 60% of their riparian area harvested hold less potential debris, more active debris, and more active debris per pool than control streams. Such streams also have debris with smaller diameters and lengths resulting in 64% of all debris occurring in an unstable state (except Deer Creek). Only Fourlakes Creek, also an intensely harvested basin, holds less LWD than its control. However, this is due to an abundance of unstable, splintered pieces which were not recorded.

Streams with less than 35% of their riparian zone harvested show little impact to LWD. Harvesting occurred mainly near first order tributaries, thus LWD within the main channel remained relatively unaffected. All LWD parameters are comparable to control streams except for potential debris, which is lower in Sunset (L) and Allen (L) Creeks.

Substrate composition remains relatively unimpacted in harvested basins compared to control streams, even though road densities are above 4.0 mi/mi^2. No significant correlation was found between monitored fines and road density, riparian disturbance or WATSED analysis. This may be a direct result of the Wolman Pebble Count technique, extensive time since road construction ceased or sediment deposition inhibited by high gradients. Still, harvested basins have slightly finer sediment than control streams. Pools and riffles in harvested basins hold 10.0 and 3.0 percent more fines respectively. However, impacts to fish are not anticipated to be severe.

Differences in channel characteristics were limited between logged and unlogged basins. Harvested basins have significantly wider channels and deeper habitats, but have similar habitat lengths. Pool area is also significantly larger in harvested basins than controls, however riffle area is similar.

Since channels in harvested basins are wider, deeper and have larger pools, I believe higher water yields are more likely to have caused changes than sedimentation. However, this is only an assumption because I cannot infer stream channel morphologies are similar. WATSED analysis predicted that only two of six harvested watersheds produced sufficient water yields over natural to modify channel form. Consequently, I feel channel modification was limited to basins with water yields greater than 10% over natual, basins with more than 30% of their area harvested, and areas with streamside harvesting which decreased rootwad/bank stability.

It appears that basin disturbance was not intensive enough to differentiate channel characteristics between harvested and unharvested streams. Basins rarely have over 30% of their surface area harvested, yet road densities are relatively high, averaging 4.3 mi/mi^2. Because LWD was not cleared and channels were not tractor-skidded, channels remained relatively unaffected at the time of harvests. I also believe basins composed of Belt geology can withstand a higher level of impact from sediment and water yields increases than other geologic types (granitics). First-order channels are well armored by bedrock and boulders. Furthermore, Belt geology has a low sediment delivery ratio compared to other geologic types during initial road construction.

Riparian harvests resulted in reduced canopy closures, earlier successional stages, and changes in overstory composition. Streams with more than 60% of their riparian zone harvested have the greatest amount of impact. This resulted in an abundance of sapling, seedling, and pole size material which provides insufficient cover compared to non-impacted riparian stands. Earlier successional stages average 30% to 50% less canopy closure than control streams. Furthermore, harvested riparian zones have 32.0% of riparian stands less than 12.7 cm DBH compared to 1% in unharvested streams. This presents a serious problem for future recruitment of adequate-size material needed for habitat formation and channel stability.

Differences between riparian understory and overstory compositions were frequent within pairs. However variations in sunlight, microclimate, and soils are probably more responsible for compositional differences than logging itself. The only measurable impact I could detect was an abundance of alder and willow in harvested riparian sites. With the removal of coniferous trees, alder and willow quickly became the dominant overstory species. Harvested riparian zones hold 20% more overstory composed of alder and willow than control streams.

Logging appeared to have no effect upon stream temperatures 15 to 30 years after harvests. Harvested basins varied by no more than 4.3°F from control basins, even though canopy closures are considerably less. Apparently sufficient vegetative cover is present to reduce shortwave radiation.

All monitored temperatures were within established limits for species present, however peaks above 60°F (15.6°C) could stress cutthroat trout. Stream temperatures and electrofishing showed that bull trout occupy cold water streams 37-51°F (3-10.5°C), while brook and cutthroat trout are more tolerant of warmer temperatures 41.6-57.1°F (5-14.0°C).

It would be interesting to repeat this study using harvested watersheds logged within the last 1 to 5 years. This would perhaps enable me to detect initial impacts from sediment and water yields upon channel characteristics. I also would have liked to have found watersheds with higher levels of disturbance. Only one stream has over 40% of its basin harvested and this is in an area of low precipitation. A greater level of disturbance, in a higher precipitation zone make channels more flashy and produced more pronounced differences. Unfortunately watershed selection was limited because controls were difficult to locate in today's managed landscapes.

I recommend that future studies concentrate on collecting variables in specific areas. For example, researchers should examine LWD, channel or riparian characteristics individually, not at the same time. This would provide the opportunity to collect variables that are more responsive to change. The role of LWD should especially be investigated; specifically bedload storage and pool formation. By focusing on specific variables, I feel we can improve our understanding of stream dynamics and improve management of our aquatic resources.

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APPENDICES

APPENDIX A

Upper and Lower Layers of Riparian Vegetation

Upper Layer: Trees or shrubs 7' tall

CM - Mesic conifer: cedar, grand fir, &/or fir (can include some spruce)
CC - Cold conifer: spruce, lodgepole pine, subalpine fir, &/or whitebark pine
CD - Dry conifer: ponderosa pine, Douglas-fir, western larch
B - Broadleaf deciduous trees: birch, white alder, &/or cottonwood
SD - Dry shrub: maple, serviceberry, hawthorn, hackberry, ninebark, oceanspray, menziesia
SR - Moist shrub: alder, willow, cascara

Lower Layer: tree seedlings and saplings, forbs, and ferns = 7' tall

SD - Dry shrub: same as for upper layer, but 2.5 - 7 ft. tall. Also includes snowberry, blue huckleberry, sticky currant, and Nevada honeysuckle
SR - Moist shrub: same as for upper layer, but 2.5 - 7 ft. tall. Also includes swamp currant, thimbleberry, swamp honeysuckle, red osier dogwood, Labrador tea, bog birch
SW - Dwarf shrub 2.5 ft. tall: willow, bog blueberry, grouse whortleberry, dwarf huckleberry
TS - Tree seedlings or saplings 2.5 - 7 ft. tall
TD - Tree seedlings les than 2.5 ft. tall
GD - Grasses (dry in the growing season) mix
GW - Grasses (wet in the growing season)
GS - Sedges (wet)

FO - Forbs
FE - Ferns
HE - Herbaceous (grass or sedge/forb
XX - Non-vegetated

Glossary

WATSED — a water and sediment prediction model developed by the Forest Service's Region 1 Watershed Unit. The model is designed to simulate the effects of water and sediment yields in watersheds.

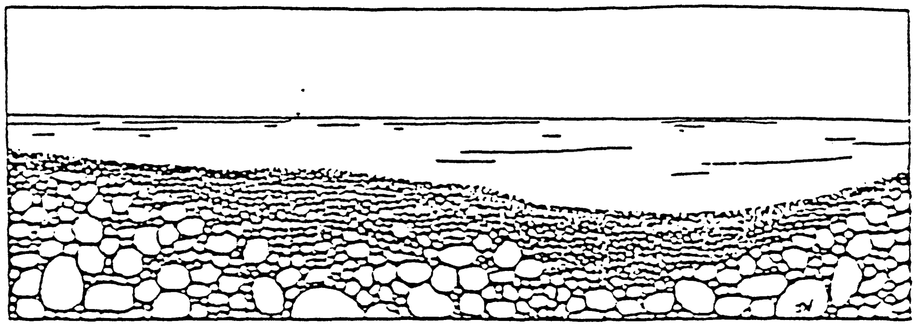
Large Woody Debris (LWD) — any stable piece of relatively stable woody material having at least diameter greater than 10 cm and a length greater than 1 m that intrudes into the stream channel.

Diameter at Breast Height (DBH) — a measurement made at breast height to determine the minimum diameter capable of withstanding natural forces and thus remain in the system.

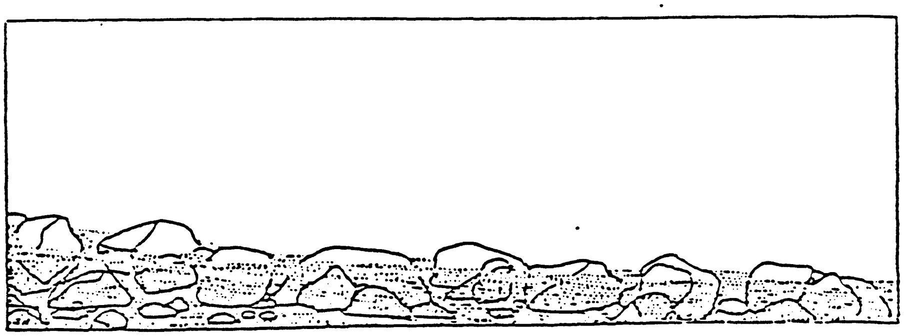
Reach — a relatively homogeneous section of a stream having a repetitious sequence of physical characteristics and habitat types.

Land System Inventory (LSI) — landforms, vegetation, precipitation and parent geology that define unique land types.

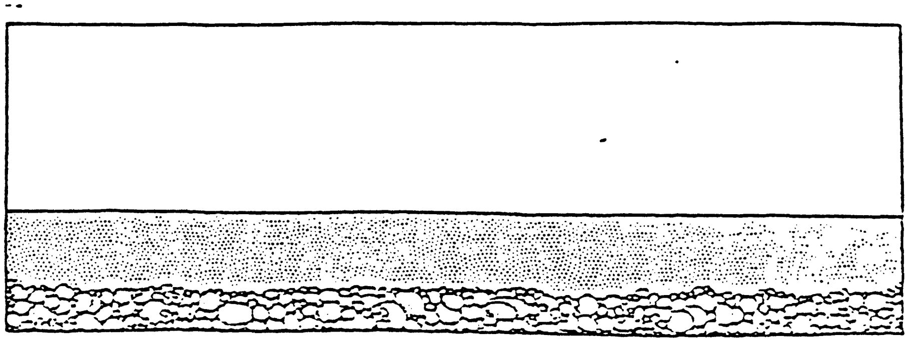
BASIC HABITAT TYPES



Pool: (a) A portion of the stream with reduced current velocity, often with water deeper than the surrounding areas, and which is frequently usable by fish for resting and cover. (b) A small body of standing water, e.g., in a marsh or on the flood plain.

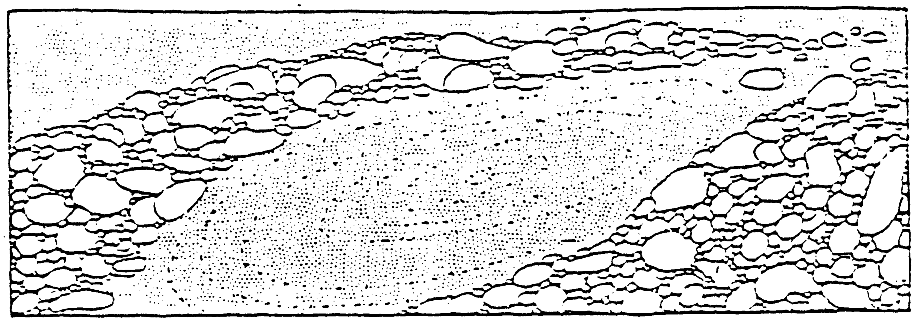


Riffle: A shallow rapids where the water flows swiftly over completely or partially submerged obstructions to produce surface agitation, but standing waves are absent.

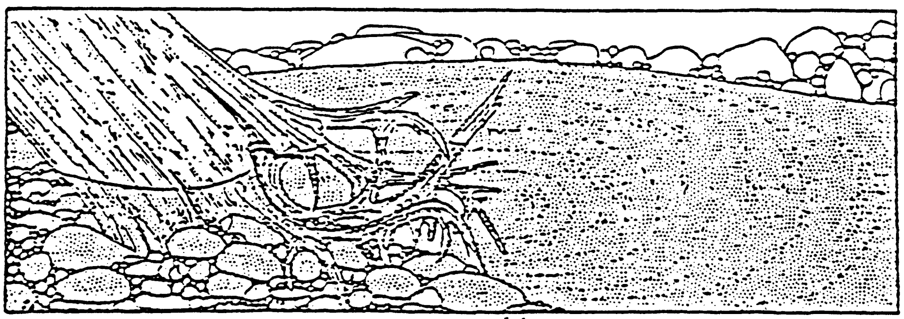


Glide: A slow moving, relatively shallow type of run. See Run. Calm water flowing smoothly and gently, with moderately low velocities (10-20cm/sec), and little or no surface turbulance.

TYPES OF POOLS

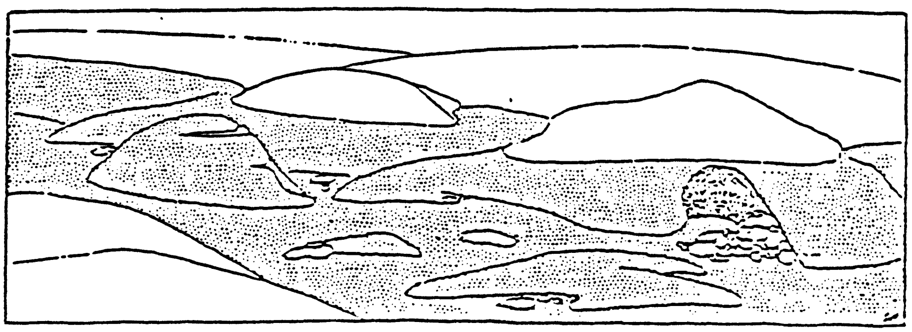


secondary channel: (Also side channel) Relatively small, sometimes isolated pools in a smaller braid of the mainstem and usually associated with gravel bars.



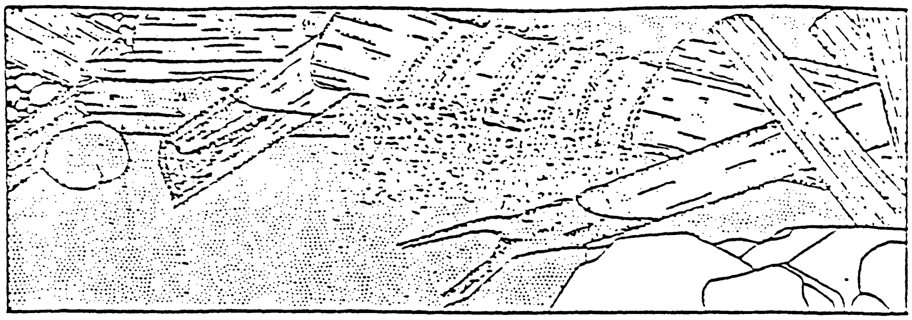
backwater: (a) A pool type formed by an eddy along channel margins downstream from obstructions such as bars, rootwads, or boulders, or resulting from back-flooding upstream from an obstructional blockage. Sometimes separated from the channel by sand/gravel bars.

(b) A body of water, the stage of which is controlled by some feature of the channel downstream from the backwater, or in coves or covering low-lying areas and having access to the main body of water.

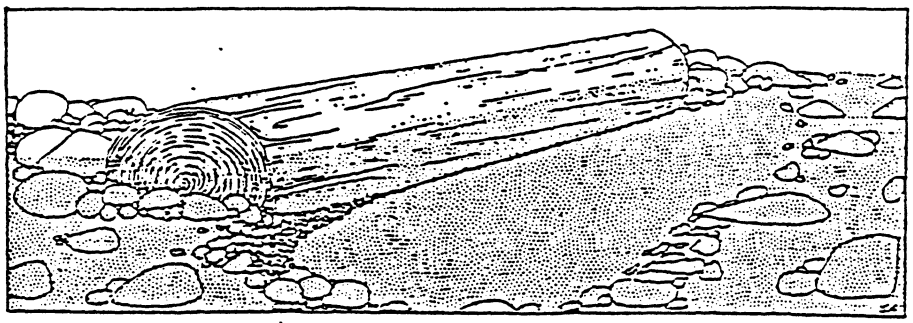


trench: A pool characterized by a relatively long, slot-like depression in the stream bed, often found in bedrock dominated channels.

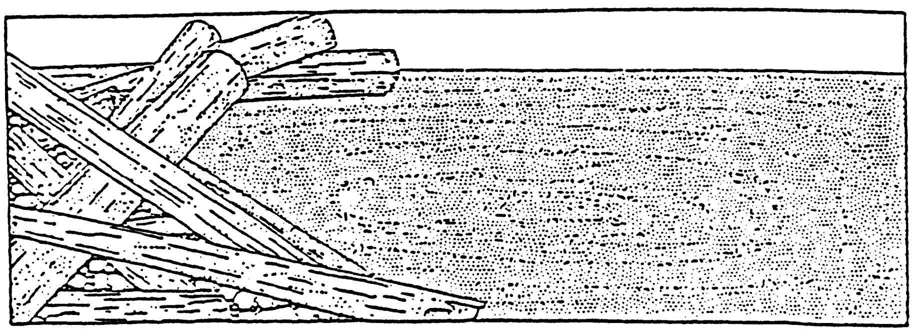
TYPES OF POOLS (con't)



plunge: (Also falls pool, plunge basin.) A pool created by water passing over or through a complete or nearly complete channel obstruction, and dropping vertically, scouring out a basin in which the flow radiates from the point of water entry.

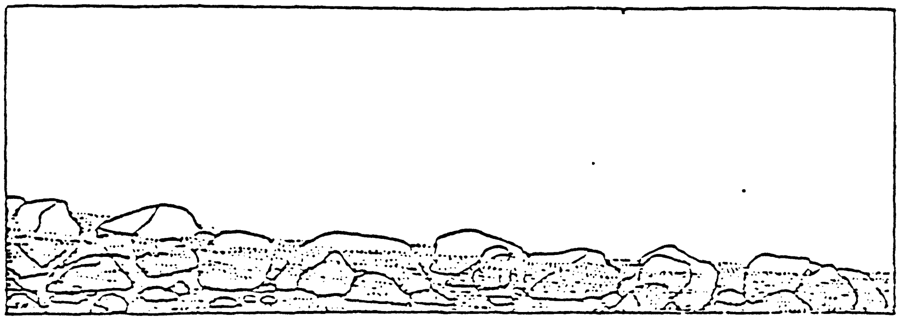


lateral scour: Formed by the scouring action of the flow as it is directed laterally or obliquely to one side of the stream by a partial channel obstruction, such as a gravel bar or wing deflector.

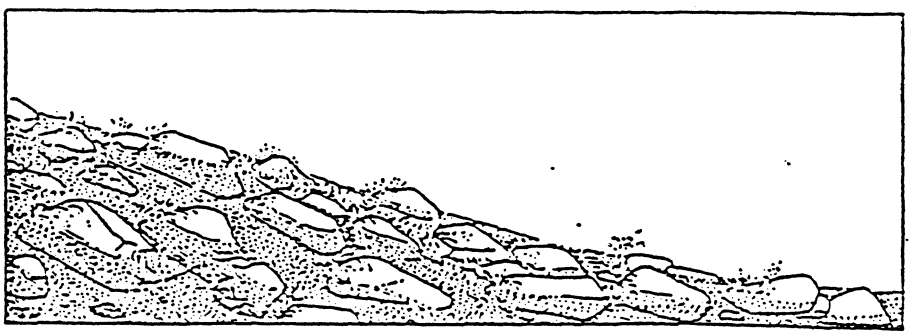


dammed: Water impounded upstream from a complete or nearly complete channel blockage, typically caused by a log jam, beaver dam, rockslide, or stream habitat improvement device (boulder berm, gabion, log sill, etc.)

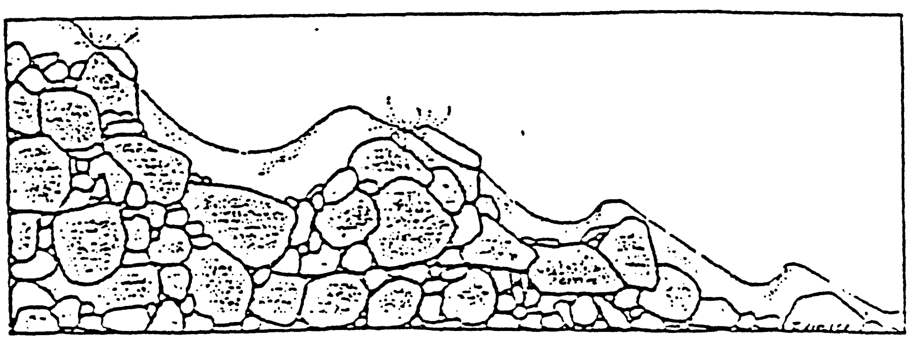
TYPES OF RIFFLES



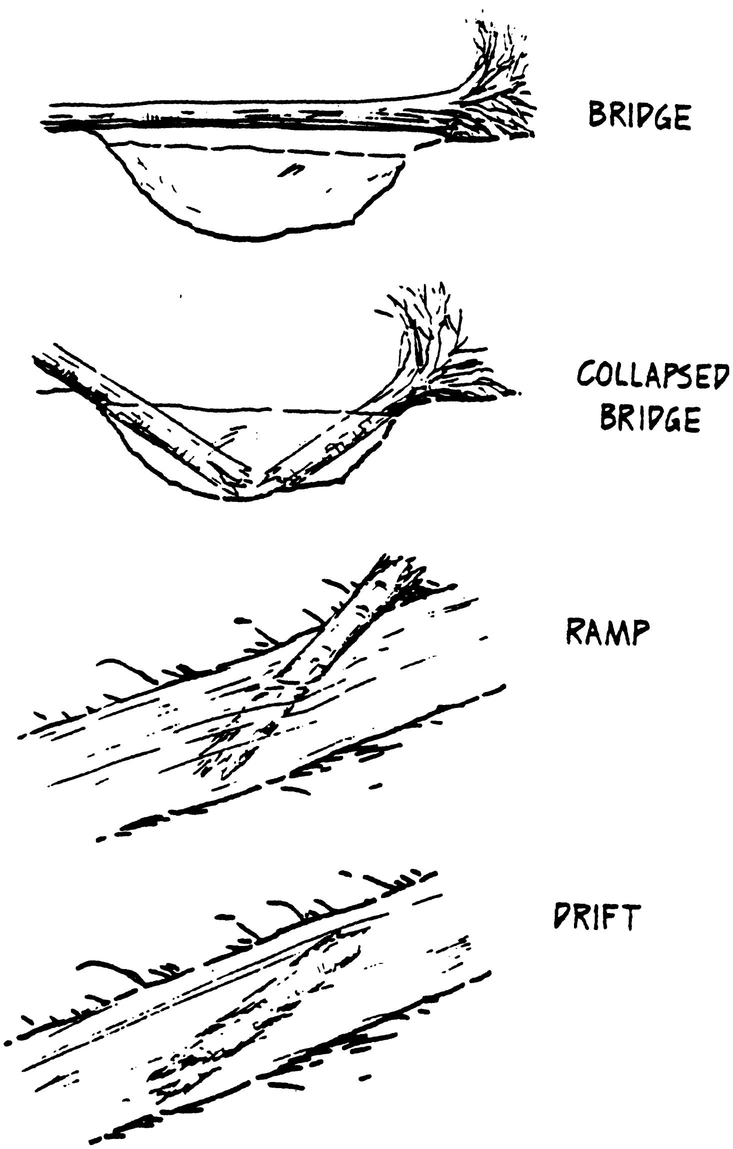
Riffle: A shallow rapids where the water flows swiftly over completely or partially submerged obstructions to produce surface agitation, but standing waves are absent.



Rapids: A relatively deep stream section with considerable surface agitation and swift current. Some waves may be present. Rocks and boulders may be exposed at all but high flows. Drops up to one meter.



Cascade: Habitat type characterized by swift current, exposed rocks and boulders, high gradient and considerable turbulence and surface agitation, and consisting of a stepped series of drops.



Four categories of large woody debris formations in streams.

Simpson's Index Simpson* (1949) considered not only the number of species (s) and the total number of individuals (N), but also the proportion of the total that occurs in each species. He showed that if two individuals are taken at random from a community, the probability that the two will belong to the same species is:

$$l = \frac{\Sigma n_i(n_i - 1)}{N(N - 1)}$$

The quantity l is, therefore, a measure of *dominance*.† A collection of species with high diversity will have low dominance, and,

$$D_s = 1 - l,$$

namely:

$$D_s = 1 - \frac{\Sigma n_i(n_i - 1)}{N(N - 1)}$$

is a good measure of diversity.†† For the data of table 5B.2,

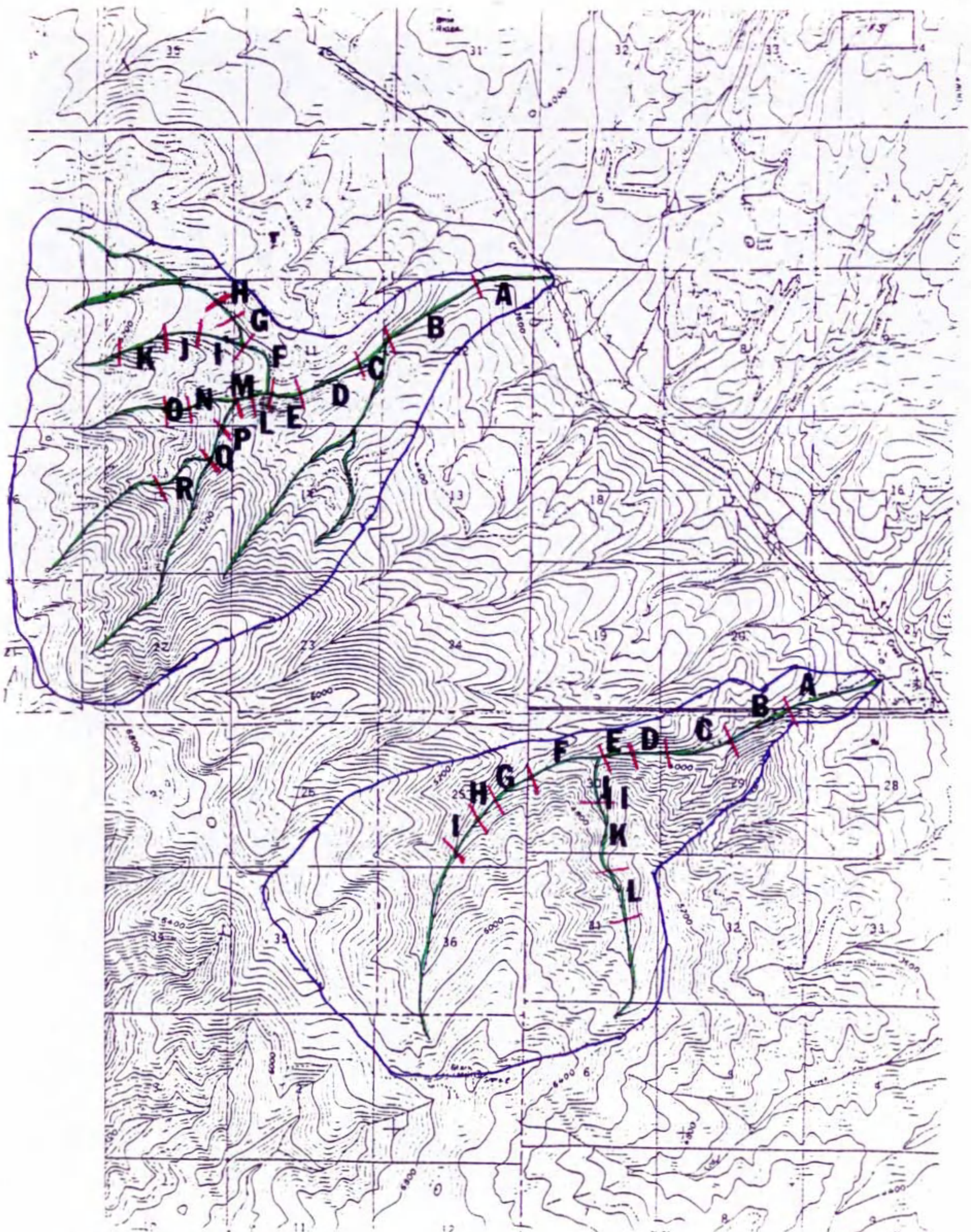
$$\begin{aligned} D_s &= 1 - \frac{50(49) + 25(24) + 10(9)}{85(84)} \\ &= 1 - 3140/7140 \\ &= 1 - 0.44 \\ &= 0.56 \end{aligned}$$

Some ecologists have inverted Simpson's dominance index to arrive at a measure of diversity:

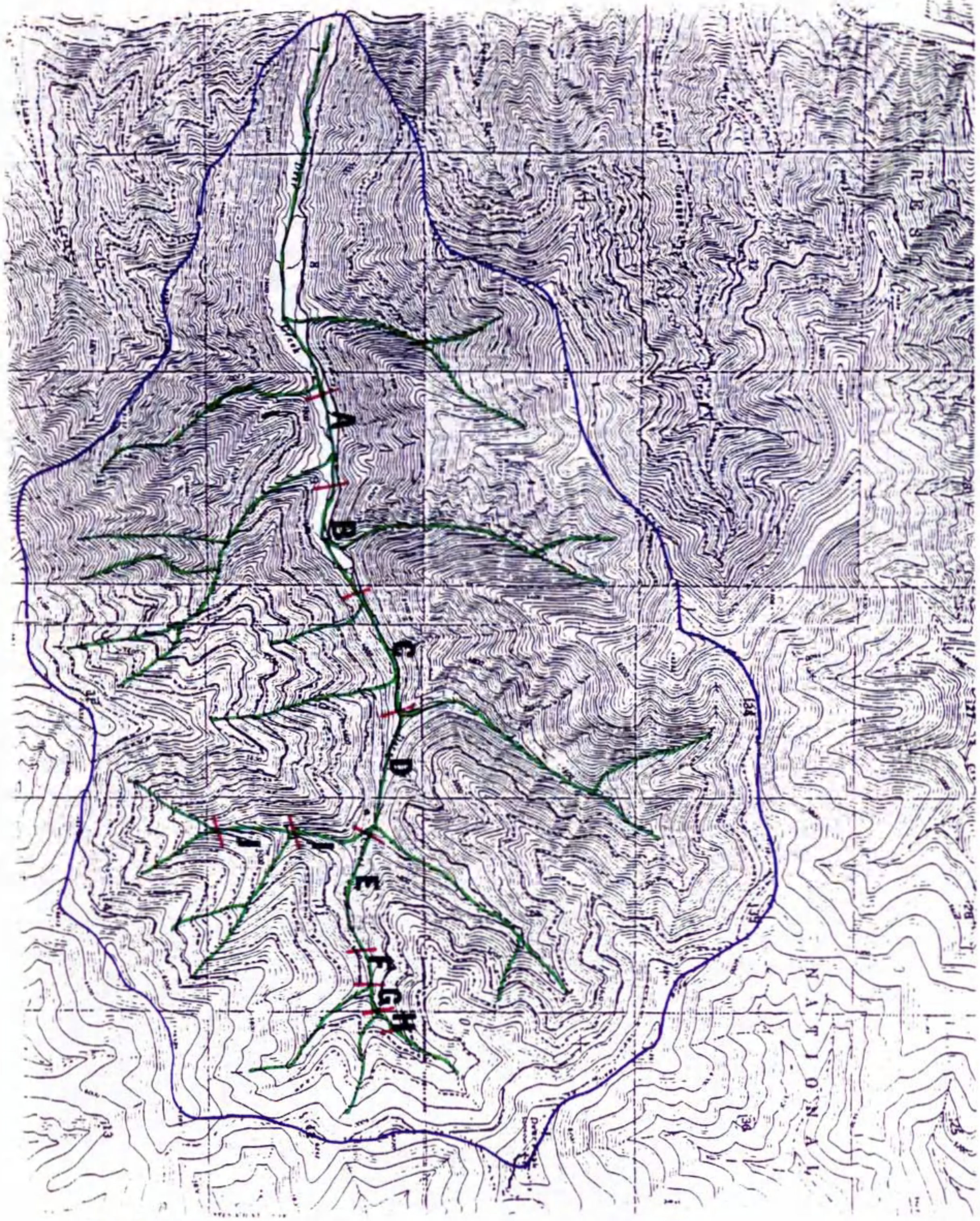
$$d_s = \frac{1}{l} = \frac{N(N - 1)}{\Sigma n_i(n_i - 1)}.$$

This diversity index is an expression of the number of times one would have to take pairs of individuals at random from the entire aggregation to find a pair from the same species. It is also an expression of how many equally abundant species would have a diversity equal to that in the observed collection.

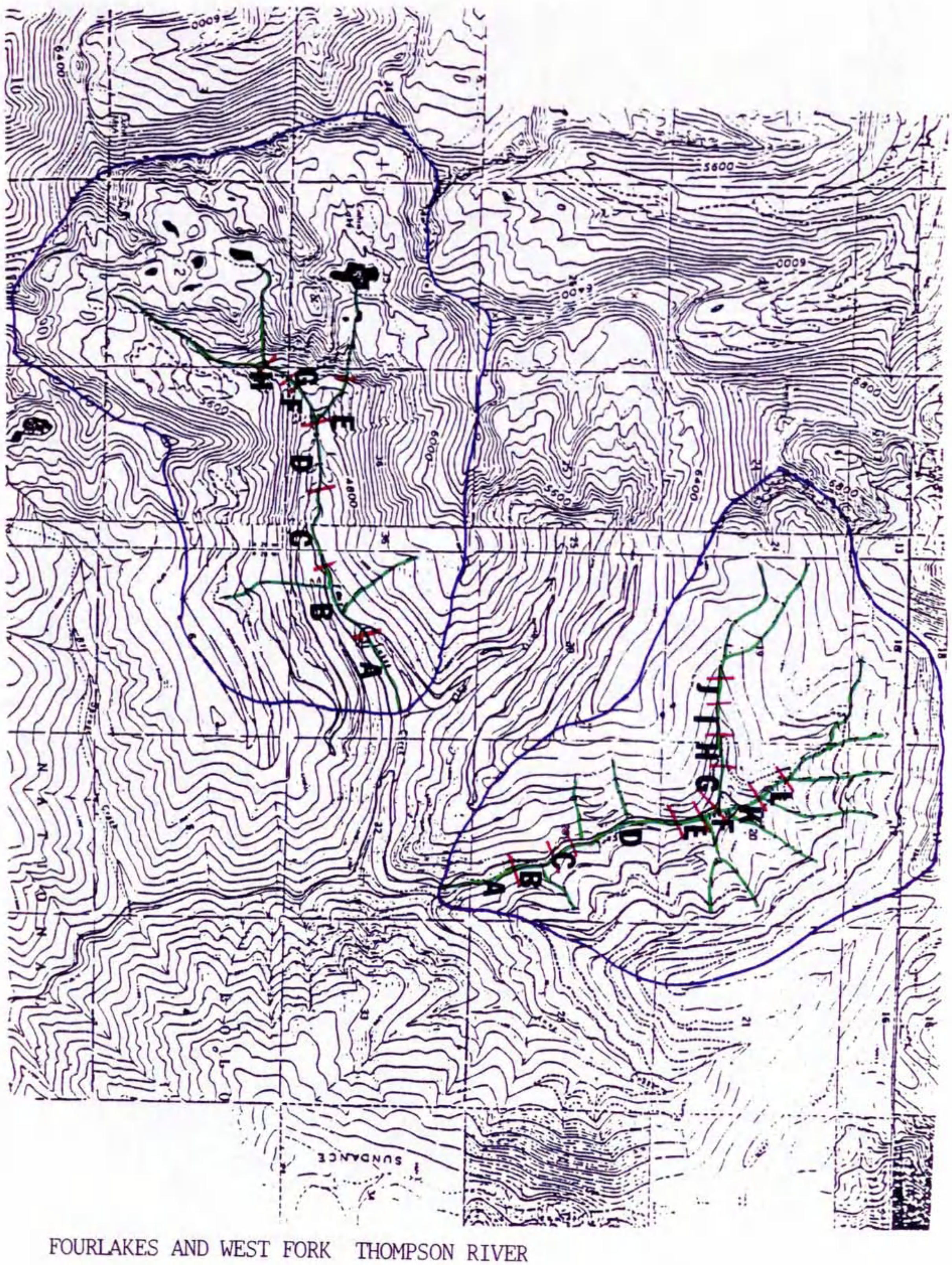
APPENDIX B



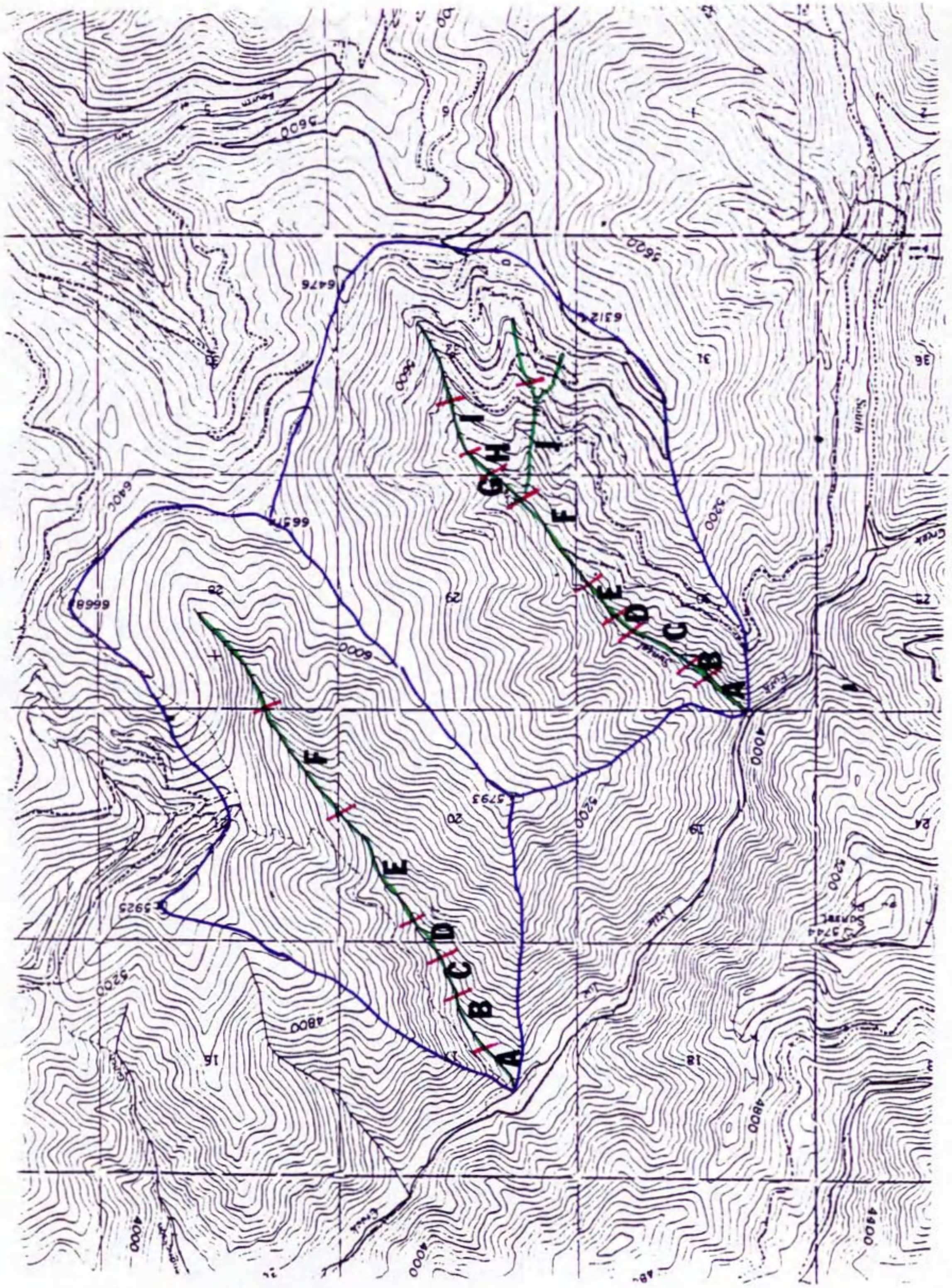
BIRD AND FIRE CREEKS



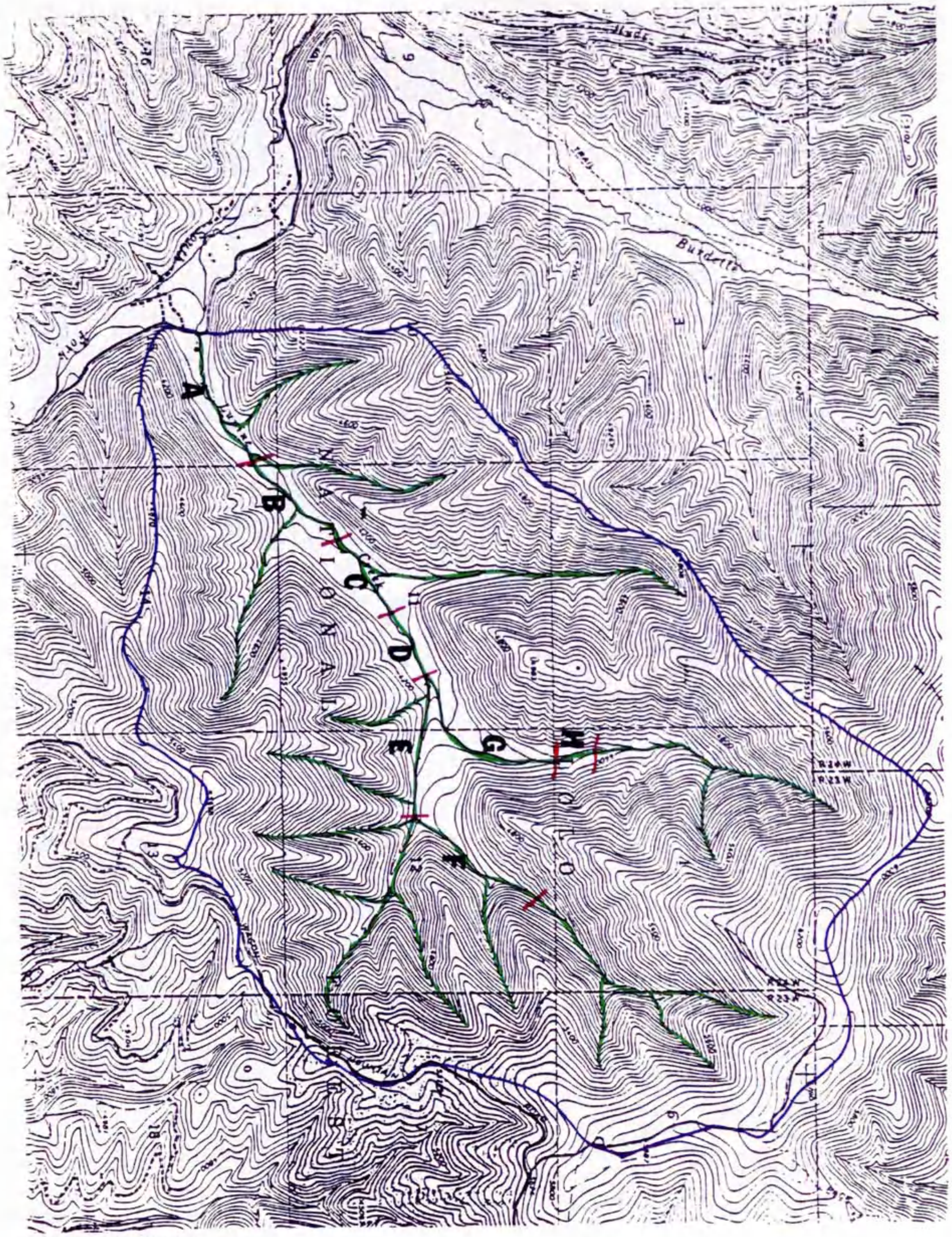
DEER CREEK



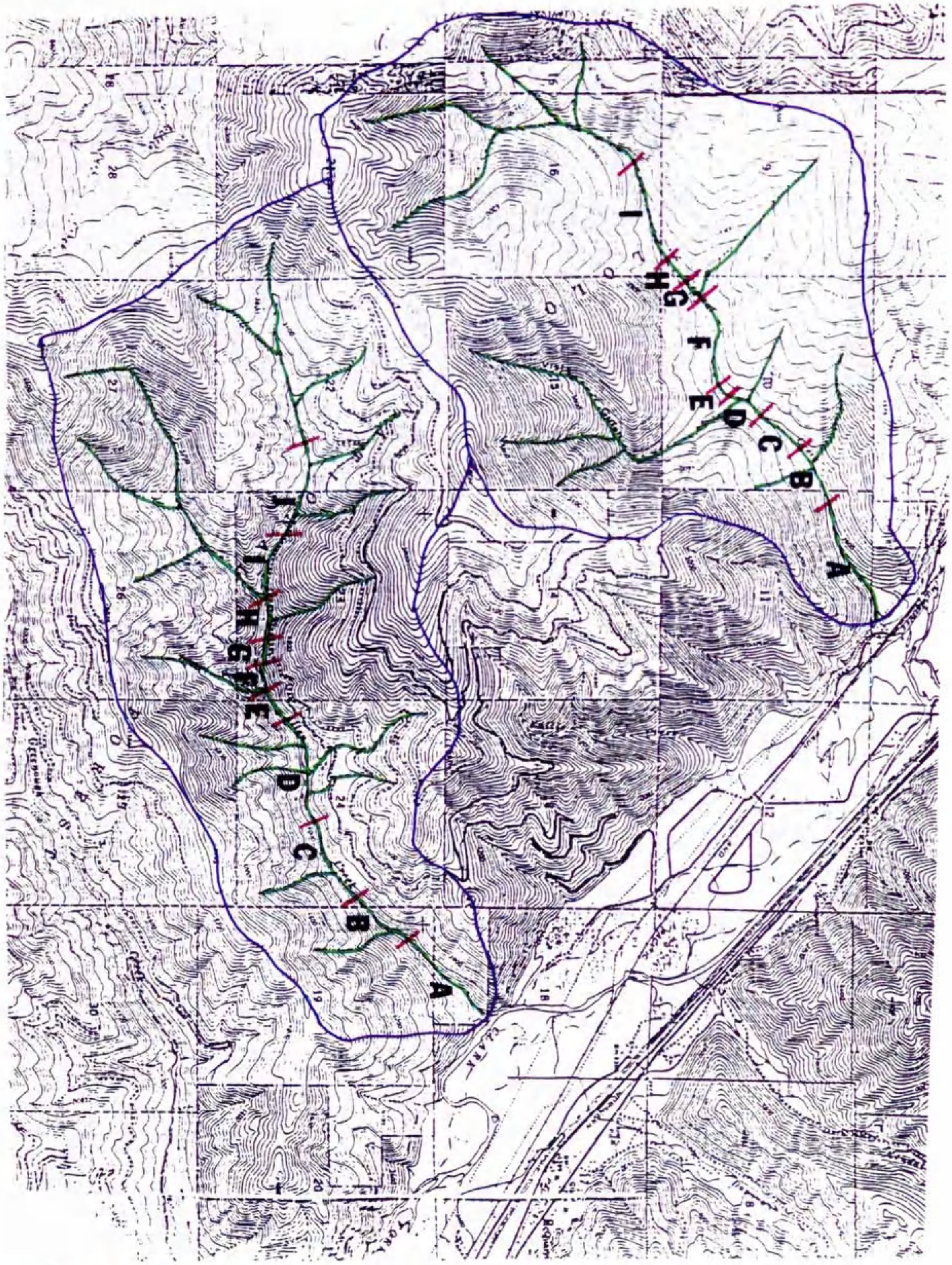
FOURLAKES AND WEST FORK THOMPSON RIVER



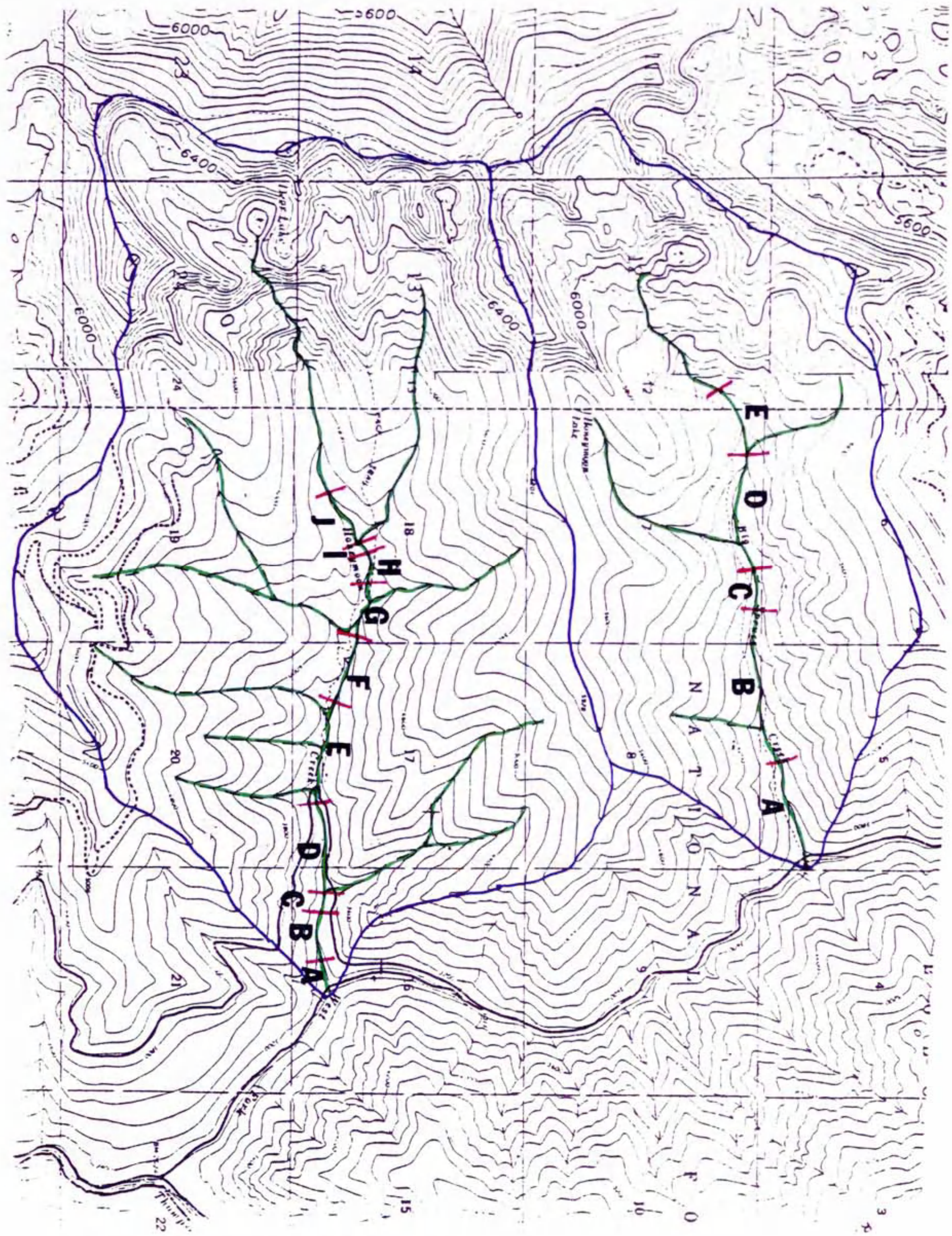
SUNSET AND JORDAN CREEKS



LUPINE CREEK



CRYSTAL AND ALLEN CREEKS



BIG SPRUCE AND HONEYMOON CREEKS